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Cost Guide

Volume 6

Cost Estimating Methods and Techniques

May 1982

U.S. Department of Energy
Assistant Secretary, Management and Administration
Office of Project and Facilities Management
Independent Cost Estimating Staff



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Washington, D.C. 20585**

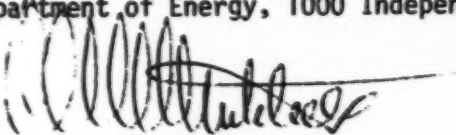


FOREWORD

Given that resources are limited and funding is austere, the cost of a project plays a major role in determining its priority and cost effectiveness relative to competing projects. If sound resource allocation decisions are to be made, cost estimates must be reliable. The purpose of this guide is to help improve the quality of our cost estimates so that Departmental decisionmakers will have a high level of confidence that the right choices are made.

This is the first cost manual published by the Department of Energy that illustrates in detail how to construct and use parametric Cost Estimating Relationships (CERs). These skills will allow cost estimators to use the CERs just developed by the Independent Cost Estimating (ICE) Staff and also will allow them to construct CERs of their own.

Comments on this guide are solicited and should be forwarded to Bobby R. Scarlett, Director, ICE Staff (MA-30.2), U.S. Department of Energy, 1000 Independence Avenue, Washington, D.C. 20585.



C. N. Mitchell, Director
Office of Project and
Facilities Management

ABSTRACT

There are many requirements for cost analysis and estimating within the Department of Energy (DOE). As projects go through the many stages of planning, source evaluation and selection, contracting, and construction, different estimating requirements exist and different techniques are available to the estimator.

This cost guide illustrates how quantity takeoff estimating is performed when adequate design data are available, and it shows how statistics can be applied to obtain parametric cost estimates. Parametric techniques will become increasingly useful as the Department's cost data base and Cost Estimating Relationships (CERs) are developed. Other cost guides developed by the Independent Cost Estimating (ICE) Staff will be published and disseminated soon.

The section on parametric cost estimating uses Department of Defense examples since the ICE Staff considered this information to be some of the best available on this subject. Also, we are indebted to several of the DOE organizations (Oak Ridge Operations Office and Idaho National Engineering Laboratory, in particular) for some of the material on quantity "takeoff" or "bottoms-up" estimating which came from their local cost manuals.

This guide was developed to assist cost estimators at all levels in the Department and comments by users are solicited.

Bobby R. Scarlett, Director
Independent Cost Estimating Staff
Office of Project and
Facilities Management

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CHAPTER I

INTRODUCTION

This volume was prepared as a textbook for Department of Energy (DOE) personnel interested in procedures for estimating the cost of construction projects. Given the many and diverse needs of DOE estimators and managers, this was somewhat of a tall order. Planners need estimates in order to weigh the benefits of various technologies, programs, and projects, and to establish energy priorities. Program and project managers need estimates for source evaluation, project baselining, budgeting, and project management and control.

Major planning decisions are often made prior to conceptual design when little design detail is available to support the estimate. As the project evolves through conceptual, Title I (preliminary) and Title II (detailed) designs, more detail is available and is required to perform the estimate. Therefore, different techniques are used at these various stages to perform the estimates. For example, a planning estimate is an order-of-magnitude estimate that can be made on a cost per square foot, linear foot, cubic yard, etc., basis. As more design detail becomes available, it becomes more desirable to make quantity takeoffs and to generally work at lower aggregate levels to construct a "bottoms-up" estimate.

The construction projects managed by DOE range tremendously in size and type. Many of our estimators are involved in estimating lower-cost projects such as warehouses, dormitories, and laboratories, while other estimators must deal with high-cost projects in such new technologies as coal gasification and magnetic fusion. The former projects generally are constructed with off-the-shelf equipment, material, and skills, and are relatively simple to construct. However, the latter often advance the state of the art, are one-of-a-kind projects, and are relatively complex to construct. Most DOE projects require conventional construction and estimating methods; however, certain production-assembly-line items such as heliostats and gas centrifuges require industrial and learning curve cost estimating methods. Accordingly, the author has attempted to illustrate basic techniques and methods that will assist the cost estimator as he addresses all these problems. This book generally deals with the cost of constructing a project. Other volumes in this series deal with life cycle cost, operating and maintenance cost, product cost, and economic analysis.

The first nine chapters of this book use typical language and techniques that are generally used by the construction industry, the various DOE organizations, and the operating contractors. As a matter of fact, some of the examples and material were volunteered from the cost estimating guides of certain DOE Operations Offices, Oak Ridge and Idaho, in particular.

Chapters 10 through 13 illustrate parametric estimating and learning curve techniques, cost modeling, and cost data bases. These techniques have been in use by the Department of Defense (DOD) and the aerospace industry for years and have produced outstanding results. Parametric estimating is extremely useful: (a) in the early stages of design when program definition is vague or incomplete; (b) in any phase, when time or resources are limited; (c) as a doublecheck against another estimate; and (d) as an indicator of areas that need further investigation.

Much of the material used in the parametric and statistical chapters is from a DOD manual developed under contract. This material was selected because it represents an outstanding treatment of this subject and no similar material could be found in the construction industry literature. The Independent Cost Estimating (ICE) Staff has been collecting cost data and developing parametric Cost Estimating Relationships (CERs) in the areas of fossil and nuclear process/powerplants and this information will be disseminated soon. The section on parametric estimating will improve the users' understanding of parametrics, immediately allow him to use the CERs developed by the ICE Staff, and will teach him to collect data and build his own CERs.

The purpose of this manual is to continue to improve the quality of cost estimating in the Department and to foster a spirit of cooperation and exchange of information among the members of the DOE cost community.

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CHAPTER 2

TYPES OF COST ESTIMATES

There are seven general types of cost estimates that are developed and used by DOE and its contractors in connection with project development and control. The types of estimates, their purposes, and their uses are described in this section. Identification of an estimate by type connotes a certain level of accuracy and confidence in the estimate.

1. PLANNING/FEASIBILITY STUDY ESTIMATES.

Planning/Feasibility Study Estimates are normally prepared by the operating contractors for a proposed project prior to the accomplishment of conceptual design. Planning estimates are used for scoping studies and for preliminary budget estimates of total project costs to be reflected in Short Form Construction Project Data Sheets. Short Form Data Sheets are prepared for identified projects and submitted to the appropriate DOE Headquarters program office for review and advice on those projects that will be supported in the budget requests, together with authorization and financing for the performance of conceptual design on each supported project. The Short Form Data Sheet will provide an estimate of funds required and a schedule for the performance of conceptual design on each project. Planning estimates are based on past cost experience with similar type facilities, where available, and order of magnitude estimates in the absence of previous cost experience. Engineering costs in this type estimate generally are based on a percentage of estimated construction costs, and consideration will be given to the complexity of the project in establishing the percentage to be used. Similarly, an allowance for contingency will be included in the total project estimate using a percentage of total engineering and construction costs established on the basis of complexity and uncertainties of the component parts of the project.

2. BUDGET OR CONCEPTUAL DESIGN ESTIMATES.

It is necessary that conceptual design be performed for each line item construction project for which it is planned to request congressional authorization and for each contingency-type project prior to requesting approval of the project. The fundamental purposes of conceptual design are as follows:

- a. Development of a project scope that will satisfy program needs.
- b. Assurance of project feasibility and attainable performance levels.
- c. Development of reliable cost estimates and realistic schedules.
- d. Baseline project definitions, schedules, and costs.

Conceptual design establishes the general criteria and design parameters, applicable codes and standards, quality assurance requirements, space allocations for required functions, types of construction, significant features and components, building and facility utility services, energy conservation goals, site work, process equipment requirements, project cost estimates, schedules, methods of performance, environmental protection requirements, decontamination and decommissioning requirements, health and safety requirements, related research and development or test programs, comprehensive project planning, and any other special requirements for the project. A Conceptual Design Report will be prepared containing the above data along with applicable drawings and outline specifications.

The completed conceptual design normally serves as the basis for preparation of a Construction Project Data Sheet Schedule 44 for the project which is submitted to DOE Headquarters for review. If Headquarters approves the project for inclusion in the budget, the project is submitted with the budget to the Office of Management and Budget (OMB) for further review, and if approved there, is included in the President's budget submittal to the Congress. When the project is approved by the Congress and funds are appropriated, OMB apportions the funds to DOE Headquarters that, in turn, issues a financial plan to the DOE Operations Office providing funds for the project. At this time, work on the project is initiated.

3. TITLE I DESIGN ESTIMATES.

Title I (preliminary) design is the initial work accomplished under an approved project. Design criteria to be following in the performance of Title I design are based essentially upon the conceptual design for the project. In Title I, the design criteria are defined in greater detail, and, if necessary, the conceptual design drawings are expanded with more detailed information including additional drawings. Also, further refined descriptive information and more detailed specifications are developed as required to serve as a firm basis to proceed with Title II definitive design. From these detailed drawings and information developed during the course of Title I design, more accurate cost estimates

and schedules are developed. The Title I design estimate normally will be prepared in accordance with the standardized construction cost code system which will permit ready comparison of the components making up the Title I estimate with those in the conceptual design estimate.

4. TITLE II DESIGN ESTIMATES.

Title II design estimates are developed for each segment of the project based on the completion of definitive design. Title II design is accomplished by the design contractors based upon the approved Title I (preliminary) design and the design criteria. Title II definitive design results in working drawings and specifications for construction work (including procurement and shop fabrication). Title II estimates are prepared in accordance with the approved Title II drawings and specifications. The Title II construction cost estimates normally would be prepared in accordance with the standardized construction cost code system which will permit ready comparison of the components of the Title I estimate.

5. Government estimates (sometimes called engineer's estimates) are used to determine the reasonableness of competitive bids received in connection with fixed-price construction contracts, and serve as a control in evaluating cost estimates prepared by a prime cost-type construction contractor. Normally, the Title II design estimate, prepared by the designer, after being reviewed and approved by the Government, is the basis for the Government estimate. However, the services of an operating contractor, OPFF construction contractor (with respect to subcontracts) or construction manager may be used as appropriate to prepare, review, or revise the Government estimate prior to Government approval. Refer to FPR 1-18.108. Cost-type contractors shall be required to follow cost estimate procedures set forth in this paragraph when subcontracting for construction services. Government review and approval of the Government estimate is not required when the estimate is within the limits established by the Government's approval of the cost-type contractors procurement system. The specifics of a Government estimate vary with the size and type of contracts as delineated below:

a. Architect-Engineer and OPFF Construction Contracts. Government estimates shall be prepared for all construction and architect-engineer contracts, except for contracts less than \$10,000. Such estimates may be revised when inaccuracies or inconsistencies are revealed during negotiations.

b. Fixed-Price Construction Contracts.

- (1) Government estimates for fixed-price construction contracts and modifications thereto shall be based on approved Title II working drawings and specifications. These estimates shall be prepared in accordance with the practices of the construction industry and in the same careful manner as if the Government were bidding in competition with private contractors.
- (2) Government estimates shall be summarized to conform with bid items but shall include the following items as backup listed separately:
 - (a) Separate estimates for alternates set forth in the bidding documents.
 - (b) A breakdown indicating quantities and unit costs for labor, materials, and equipment entering into the work.
 - (c) Estimates for mobilization, demobilization, etc.
 - (d) Allowance for contractor's overhead and profit, including the cost of such items as sales tax, insurance, and bonds.
- (3) Government estimates shall be prepared independently in advance of any bid or solicited proposal submitted by a prospective contractor or subcontractor.
- (4) Prior to opening of bids, access to or disclosure of information concerning Government estimates shall be limited to personnel requiring such information in performance of their duties.
- (5) Government estimates for formally advertised or competitive proposal fixed-price construction contracts shall not be changed after the opening of bids or proposals except where careful reexamination indicates a definite error. In the event an estimate is changed under such circumstances, detailed reasons for the revision shall be documented.

c. Estimates for Minor Projects. The preparation of Government estimates in connection with work estimated to cost less than \$10,000 is optional with the field organization manager. Where the field organization manager elects to use a contractor's estimate, bid, or proposal instead of a Government estimate under this limitation, the contractor's estimate shall be carefully evaluated to verify that it is fair and reasonable.

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6. CURRENT WORKING ESTIMATES.

These estimates are required for cost control on construction projects and are conducted periodically throughout the life of the project from the completion of conceptual design until final completion of construction. It is necessary that working estimates be kept under constant review to assure that they reflect the latest cost and design data available, the estimated cost to complete, the allowance for contingency based on detailed contingency analysis, and the uncertainties remaining under the project.

7. Independent Cost Estimate is a documented cost estimate that has the express purpose of serving as an analytical tool to validate crosscheck, or analyze estimates developed by proponents of a project. An independent cost estimate also serves as a basis for verifying risk assessments.

These estimates may be performed by the Independent Cost Estimating Staff in support of key decisions by the Under Secretary, or they may be initiated by an Assistant Secretary, program manager, project manager, or some other advocate as a check against the project estimate.

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CHAPTER 3

BASIS FOR THE COST ESTIMATES

When cost estimates are prepared for projects, a description of the basis for the cost estimate will be made and included in the estimate documentation. The general requirements for each type of cost estimate are as follows.

1. PLANNING/FEASIBILITY STUDY ESTIMATES.

The basis for the cost estimate must describe the purpose of the project, general design criteria, significant features and components, proposed methods of accomplishment, proposed construction schedule, research and development requirements, and any other pertinent cost experiences.

2. BUDGET OR CONCEPTUAL DESIGN ESTIMATES.

The basis for these cost estimates must include all the detailed requirements in the Conceptual Design Report (CDR), such as the design parameters, applicable codes, specifications and standards, QA requirements, space requirements, research and development requirements, methods of performance, operations interfaces, safety requirements, etc.

3. TITLE I DESIGN ESTIMATES.

The basis for these cost estimates must include all the bases mentioned in the CDR estimate basis, plus all the refinements developed during the course of producing the Title I Engineering package. This includes all drawings, outline specifications, data sheets, bills of material, schedule refinements, definitions of scope, methods of performance, changes in codes, standards, and specifications.

4. TITLE II DESIGN ESTIMATES.

The basis for these cost estimates must include all the approved engineering data, methods of performance, final project definition and parameters, project schedule, and final exact detailed requirements. The statement of "basis" should include a complete list of all engineering data used; i.e., drawing data sheets, specifications, bills of material, job instructions, proposed schedules, etc.

5. GOVERNMENT OR ENGINEER'S ESTIMATE.

Since this estimate is simply a refinement of a Title II design estimate, the basis or logic used to make adjustments or refinements must be listed and made a part of the file.

6. CURRENT WORKING ESTIMATES.

The basis for these cost estimates must carefully define the purpose and scope of the estimate along with a complete list of all the considerations used to develop the estimate for costs experienced to date and data used to complete the projections.

CHAPTER 4

PLANNING FOR THE ESTIMATE

The following guidelines are provided for planning the various estimates.

1. PLANNING ESTIMATE.

- a. Requirements. Sufficient criteria must be provided to enable the estimator to prepare a planning estimate. This criteria can range from the functional/operational requirements to a brief description. The description might be supplemented with a sketch, a tour of the proposed project site, or references to similar projects which are already existing.
- b. Guidelines. A planning estimate is an order of magnitude estimate; it can be estimated on a per square foot, linear foot, cubic yard, KW, etc., basis. The estimator should get all available information about the project from the requester. On many projects, the available data will be minimal and only an allowance can be made for various segments of the estimate. It is imperative that the estimator fully describe the basis of the estimate. How the estimate was prepared and any items specifically excluded must be noted.
- c. The Standardized Code of Accounts should be used on the planning estimate for three reasons. One, it provides a uniform system of estimate breakdown. Two, it can be used as a checklist to eliminate oversights and omissions. Three, is a simplified comparison of actual costs against estimates made at various stages.

2. CONCEPTUAL ESTIMATE.

- a. Requirements. The conceptual design sketches and specifications as well as the functional/operational requirements should be available to the estimator prior to developing the conceptual estimate. Where possible, this information shall be supplemented with a tour of the proposed site. Site drawings can be used as a reference for details of construction and for quantity take-off. These reference drawings are very helpful when estimating demolition.
- b. Guidelines. The request for funding is based on the conceptual estimate. The estimate should incorporate all details available as well as a detailed breakdown of any allowances used. The estimator must fully document the basis of the estimate including sources of quotations, assumptions, and any items specifically omitted.
- c. The Standardized Code of Account should be used on conceptual estimates for two reasons. One, it provides a uniform system of estimate breakdown and, two, it can be used as a checklist to eliminate oversights and omissions.

3. TITLE I ESTIMATE.

- a. Requirements. The Title I estimate is based on the Title I drawings and specifications. In addition to the Title I drawings and specifications, the estimator should have access to the design criteria conceptual estimate, and the functional/operational requirements. A tour of the site and reference drawings of the construction site shall be used in preparing the estimate.
- b. Guidelines. The Title I estimate is an estimate of construction cost. At this point in a project, the engineering design, inspection, and project administration costs have been allocated and only need to be verified. The total project cost has been determined from the conceptual estimate so the Title I estimate is an intermediate estimate to verify that the Title I design details still remain within the project funding. Title I estimates should be broken down into the Code of Accounts and the costs obtained as described in the Performing the Estimate section of this manual. A Title I estimate will have more detail available than a conceptual estimate and this additional detail should be shown.

4. TITLE II ESTIMATE.

- a. Requirements. The Title II estimate is based on the Title II drawings and specifications. This estimate should approximate the construction bids which will be received for this project. The estimator should have the Title II drawings and specifications the Title I estimate, the functional/operational requirements, and the tentative construction schedule, before generating the Title II estimate. A project site tour should be made if the estimator is not completely familiar with the construction area.

- b. Guidelines. The Title II estimate is a refinement of the Title I estimate. The Title II estimate should be broken down into details. Allowances should only be used on minor items whose total is an insignificant portion of the total cost. Engineering design, inspection, and project administration costs only need verification at this point.

Title II estimate details should be broken down as described in the Code of Accounts.

5. GOVERNMENT ESTIMATES.

Government estimates should basically be performed in the same manner as Title II estimates.

CHAPTER 5

PERFORMING THE ESTIMATE

1. CONSTRUCTION COSTS.

a. Direct Costs.

- (1) The determination of direct costs is the beginning of estimate preparation. The items considered as direct costs vary with the type of contract. On a fixed price or lump sum contract, the direct costs are those costs for material and labor including payroll burden. On a cost plus fixed percentage or force account contract, the direct costs are the costs for material and labor, field and home office expenses, accounting, secretarial, payroll burden and equipment. On a cost plus fixed percentage or force account, the only cost not considered as direct costs is the fee.

- (2) The following steps are used in the determination of direct costs.

- (a) A material, labor, and equipment takeoff is developed from the drawing and specification review. This list is divided into categories called accounts, and each account has subaccounts. The accounts are shown in Cost Codes for Construction Projects. The amount of detailed takeoff will vary with the amount of design detail. A planning estimate has minimal detail, while a Title II estimate has a great deal of detail. Each account should be considered even on planning estimates to help eliminate any omissions or oversights. By listing the accounts you have a checklist of potential items included in an estimate.

- (b) The next step is to price the individual items. On fixed price or lump sum contracts, the material cost should be the cost a contractor will pay for the material. This does not include any markup of handling by the contractor. Freight to the job site is included.

Several acceptable ways of pricing material are by verbal or written vendor quotations, up-to-date catalog price sheets, estimating manuals, and historical data. When using quotations for materials, use the current material price whenever possible. If old prices are used, escalation must be added to make the prices current as of the estimate date. Escalation beyond the date of the estimate is included as a separate item. Material and equipment that is specified as Government Furnished Equipment (GFE) should be identified and kept separate from contractor furnished material.

- (c) After the materials and equipment have been priced, the installation cost must be estimated. The installation costs include all labor costs and special tools or equipment required for installation of the items. To properly determine the installation costs, the estimator should build the project in his mind. The most accurate method of determining labor cost is to determine the man-hours required for installation and multiply them by the applicable costs of labor. For ease of estimating, an average crew rate can be used and rounded to the nearest even dollar hourly rate. The direct costs of labor are the sum of the workmens' base rate plus all payroll indirect costs.

- (d) Some fixed price or lump sum contract projects require special tools or equipment for completion of the work. An example of this is a HVAC project might require a large crane for setting an air handling unit on the roof. The cost of the crane would be considered special equipment and the cost for the crane will be a direct cost and is put in the column title "other" on the estimate detail sheet. Examples of non-special equipment are small tools and pickup trucks and are to be included in the indirect costs. On cost plus fixed percentage contracts, all costs for equipment, tools, and indirects are considered as direct costs.

- (e) Consideration must be given to all factors that affect construction. Some of these factors are:

- 1 Availability of skilled and experienced manpower and their productivity.
- 2 The need for overtime work.

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- 3 The anticipated weather conditions during the construction period.
 - 4 Work in congested areas or in radiation areas.
 - 5 Security requirements imposed on the work area.
 - 6 Use of respirators and special clothing.
 - 7 The state of the general economy.
 - 8 The type and quality of project supervision.
 - 9 Equipment to be delivered for best construction sequence.
- (f) There are several good publications which provide an estimate of the labor hours required for a task that the estimator should use unless adequate experience has given the estimator a more accurate base for determining labor hours required. One important item which must be remembered when using general estimating publications is that these publications are based on a national average construction project for private industry. The situation at various DOE sites may not be the same as an average construction site. Some examples of possible differences are: (1) security area, (2) remote location, (3) nuclear radiation areas, (4) degree of inspection, and (5) documentation, etc. For reasons like this, local productivity studies can be constructed which monitor the productivity at the specific site versus the labor hours given in the general estimating publications. If an estimate is derived using the publications, the site productivity factor must be incorporated into the estimated man-hours. This should be done prior to multiplication of the man-hours by the labor rate.
- (g) Labor and equipment costs for installation of Government furnished materials must be included for each item. These costs should be included under the appropriate general account category.

b. Indirect Costs.

- (1) Indirect costs like direct costs vary with the type of contract. If the contract is a cost plus fixed percentage type, the only item of indirect cost is the fee. All other costs are listed as direct costs. When estimating a profit which will be constructed by a cost plus fixed percentage contract, a fee of 2% of the direct costs should be used.
- (2) On a fixed price or lump sum type of contract, the indirect costs are the contractors' costs for general administration. They include field overhead, office expenses, temporary construction, small tools, profit, bond, etc.

(a) Overhead includes but is not limited to the following:

- 1 Non-specialized Construction Equipment. This equipment is that which is used throughout the project and not specifically for any one task. An example of this is the foreman's pickup truck, small tools, etc.
- 2 Field Overhead. These people are the construction project manager, superintendent, engineers, safety personnel, equipment mechanics, timekeepers/accountants, secretary, and warehouseman. The cost for all contractor personnel whose job location is the job site and who are not directly performing construction activities is included in field overhead.
- 3 Office Overhead. These people are the procurement agent, expeditor, secretary, accountants, and estimator. On large projects, some of these functions are performed by the field overhead personnel.
- 4 Temporary Facilities. The construction supervisory personnel need office space at the job site. This is not normally provided by the customer; hence, the contractor is responsible for furnishing an office. This office space can range from several office trailers to using a pickup truck, depending on the project size and number of construction supervisory personnel. Other temporary facilities typically include electric service, water service, heating and cooling, furniture and fixtures, janitor services, signs, temporary toilets, and warehouse.

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5 Supplies. The contractor is required to furnish various supplies. Some typical supplies are plans, specifications, shop drawings, as-built drawings, photos, stationary, postage, drinking water, ice, dispensers, first aid, and fire protection equipment. Small tools are also provided by the contractor. These are items like hammers, blades, bits, shovels, slings, bars, cutters, clamps, fuels, lubricants, and ladders.

6 Insurance and Bonds. The typical insurances required are truck and auto, public liability, builders' risk and performance bonds.

7 Move-in/Move-out and Job Cleanup. When a contractor is successful in being awarded a contract, he encounters move-in costs. These costs are for transportation of equipment, facilities, and supervisory personnel to the construction site. At the completion of the project, the temporary facilities and equipment brought to site will have to be removed. During construction, debris must be disposed of and the site cleaned of construction materials and debris.

(b) Profit. The contractor's profit is the money he receives for the use of capital, his expertise, and benefit for being in business. This is normally a small percentage of the total project cost. The contractor's profit will vary depending on the quantity of work, the length of project, and the amount of risk.

(c) Determination of Indirect Costs. The indirect cost can be determined by two different methods. The first and most accurate method is to assign costs to each component of the indirect costs as described above. This can be a lengthy list and has to be based on a particular size and type of contractor. This method of determining indirect costs requires a great deal of construction experience and a working knowledge of a construction firm's procedures. The second method is to use a multiplier from a chart developed from local data. The following chart is an average of what the various fixed price contractors currently working at the INEL use for indirect costs. To use the chart, the ratio of direct cost material to labor must be determined. This ratio is located at the bottom of the graph. A vertical line is drawn from this point to intersect with the curve. The multiplier is read on the left-hand side of the graph and this multiplier is applied to the direct cost to determine the estimated indirect cost. All Operations Offices and Labs are encouraged to develop these local charts.

(d) If a project has "Government Furnished Equipment and Materials" that the contractor must install, an additional, say 5 percent to 10 percent of the value of the GFE, must be added to the indirects determined above. This percentage covers the contractors risk, insurance, and paperwork required in handling GFE.

c. Construction Manager.

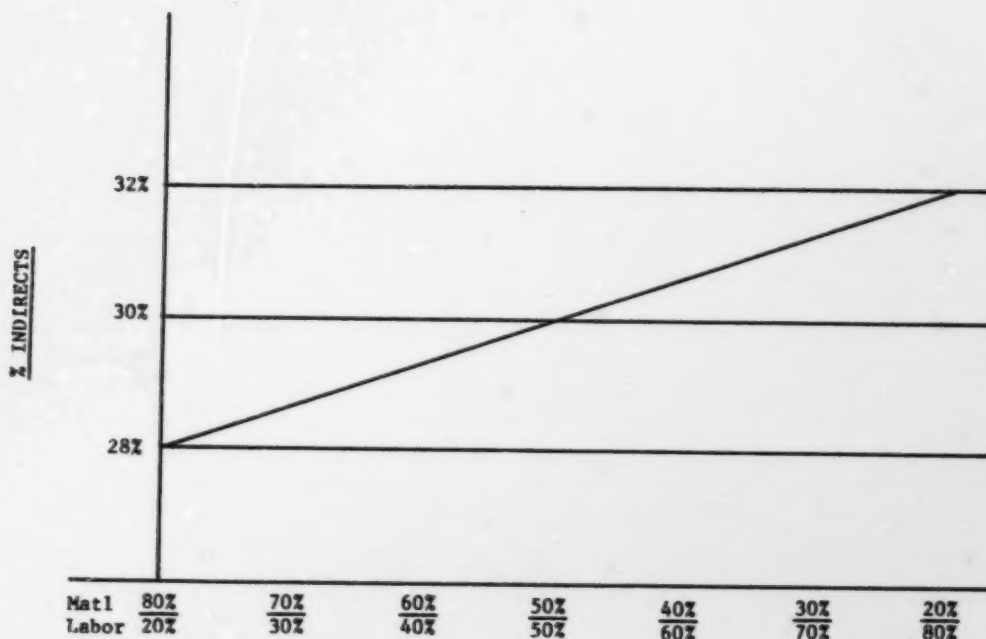
- (1) A Construction Manager (CM) is responsible for construction activities. This responsibility includes subcontracting, purchasing, scheduling, and a limited amount of actual construction.
- (2) The cost for the CM is approximately 14 percent of the sum of direct costs, indirect costs and GFE procured by the CM. If the GFE is not procured by the CM, it is exempt from his fee.

d. Engineering Design and Inspection (ED&I).

- (1) Engineering and design costs are directly related to the magnitude and complexity of the project. Specifically, the following items should be considered.
 - (a) Comprehensiveness of Functional/Operational (F/O) Requirements. Project understanding is improved when comprehensive F/O requirements are provided. For the F/O requirements to be well done, each item needs to be thought through by those who review the design and will use, operate, and maintain the facility or system.
 - (b) Quality Level. Quality level as defined below, is significant particularly as it effects the analysis, documentation, and inspection required. Design costs are increased by the additional work that may be required by the following levels:

Quality Level I. Applied to nuclear system, structure, subsystem, item, component, or design characteristics which prevents or mitigates the consequences of postulated accidents that could cause undue risks to the health and safety of the public.

Indirect Costs



Quality Level II. Any other system, structure, subsystem, item, or component which as a result of failure could cause degradation of required performance, such as plant operation, test results, and performance data.

Quality Level III. Items designated for minimal impact applications.

- (c) Design Planning Tabulation (DPT). The DPT sets forth a number of important items that affect ED&I costs. The DPT sets the code requirements the design will meet, reviews to be held, quality levels and documents to be issued.
- (d) Design Layout. Design layout costs are affected by the availability of existing documents and the accuracy of these documents. The need for an engineer to make detailed layouts rather than having it done by draftsmen/ designers also affects cost.
- (e) Engineering Calculations. The amount and detail of calculating required is an important engineering cost factor. The need for review of these calculations by others and their documentation and storage can affect ED&I cost significantly.
- (f) Drafting. The drawing format and the method of accomplishment of the work depicted (i.e., by maintenance, lump sum construction contract, or cost plus construction contract) will affect the detail and time required to prepare drawing(s). The type of drawing and the discipline of work are also big factors in time required. The number of drawings involved is a direct indication of drafting time and cost. The availability of standard details, etc., can reduce costs appreciably. Quality Levels I or II requirements can also add to drafting requirements and thus time.
- (g) Specification Preparation. The availability of draft specifications for the items of work involved or the need to develop new specifications must be considered. Projects requiring preliminary proposals require both an outline specification, which is normally prepared with Title I, and a detailed technical specification. Performance

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specifications for both the design and installation by a subcontractor of facilities and systems, such as fire protection, will reduce engineering costs. Design costs incurred by the subcontractor are classified as subcontract construction costs.

- (h) Checking. The need for field investigation can be a significant engineering cost. If drafting must be checked by checkers within that section, the time must be considered and costs added. Projects requiring interdiscipline checks must have time/cost provisions. Checks made by engineers must also be considered.
 - (i) Cost Estimating. Time required for estimating is affected by the detail of the project, particularly the number of items involved and the areas in which good information from historical data or test books on cost are available. Speciality items usually require additional effort and cost.
 - (j) Design Reviews. The number of design reviews and action taken will affect costs. If the design is so formal that a committee is established for the review and the designers must present their designs step by step, the additional costs required for review must be included.
 - (k) Safety Analysis Report. When a safety analysis report is required, the engineering costs are contingent upon similar documents having been prepared previously or the requirements to develop new ones.
 - (l) Reports. Engineering costs for preparing reports such as preliminary proposals, design status reports, etc., must be included in the ED&I funds.
 - (m) Government Furnished Equipment (GFE). Engineering costs for providing documents required for procuring GFE items must be included. These costs include specifications. Time required for engineering is more than if the item had been included with the other technical documents due to document control and the need to include in the technical documents information on the item being furnished.
 - (n) Off-Site A/E. If an offsite A/E is to be used for the design, travel costs for field investigation, design reviews, and management of the design should be considered. Cost is percentage of construction cost. If changes are required, onsite A/E may have to make the changes which could lead to problems in interpreting or understanding the basis of the original design.
- (2) Inspection (included as part of Title III) of all construction work including procurement and installation of associated equipment shall be conducted in all cases prior to acceptance. Inspection should be made at such times and places as may be necessary to provide the degree of assurance required to determine that the materials or services comply with contract and specification requirements, including quality level requirements. The type and extent of inspection needed will depend on the nature, value, and functional importance of the project and its component parts, as determined by project requester/proposer. Specifically, the following should be considered.
- (a) Duration. Duration is the number of actual construction days anticipated for the project. Delays in startup, waiting for materials, is not included in this duration.
 - (b) Labor Density. Labor density is the ratio of estimated costs of materials to costs of labor. In general, construction with a high labor density will require more inspection.
 - (c) Complexity. A project having a high degree of instrumentation of a large amount of "code equivalent" welding will require more inspection per dollar of labor than will earth work or ordinary concrete work.
 - (d) Overtime. The time schedule of utility outages, reactor windows, and the overall project schedule may require overtime.
 - (e) Adequacy of Plans and Specifications. If the technical package is clear, with a minimum of ambiguities and will require few field changes, the inspection cost will be lower.
 - (f) Offsite Fabrications. Inspection costs will increase if source inspections are required. Supplies and services shall be inspected at the source where:

- 1 Inspection at any other point would require uneconomical disassembly or nondestructive testing;

- 2 Considerable loss would result from the manufacture and shipment of unacceptable supplies or from the delay in making necessary corrections;
- 3 Special instruments, gauges, or facilities required for inspection are available only at source;
- 4 Inspection at any other point would destroy or require the replacement of costly special packing and packaging;
- 5 A quality control system is required by the contract or inspection during performance of the contract is essential;
- 6 It is otherwise determined to be in the best interest of the Government.
- (g) Location of the Job. Travel time to and from the job must be taken into consideration.
- (3) As a guideline, ED&I costs have been between 15 percent and 26 percent of the total construction cost for detailed design.
- (4) An option to detailed design is the use of a performance specification. This type of specification requires the subcontractor to supply the amount of detail he requires to complete the project. The amount of ED&I required for a performance specification is appreciably less than that required for the detailed design.
- e. Project Administration.
- (1) Project administration encompasses the following functions that must be allocated from project funds.
- (a) Project Management. The estimate for project management must consider the time element from start of Title I design through completion of the construction for the project. Other factors to consider are the complexity of the project, the design group, the organization for which the project is to be performed, and the extent of procured items. Projects involving travel must have funds included.
- (b) Construction Coordination. Construction coordination includes a field engineer. The field engineer should be involved in the review of the Title I and II documents, as well as coordinate field construction.
- (c) Quality Engineering. For the quality engineering estimate, define the tasks for the project and negotiate the man-hour effort with the quality organizations. The estimate will depend upon the quality level of the project, the amount of procurement effort and level of involvement of the quality inspection organization. Where the latter is involved, quality engineering is responsible for the preparation of the quality plan. Travel must also be considered. The portion of quality engineering which is an audit function is not funded by construction and need not be included in the estimate.
- (d) Health Safety. This function is involved with the review and approval of the design package as well as the safety audits and health physics surveillance throughout the course of the construction period. Factors affecting this element are the type of project, operational area where the construction takes place, the amount of work requiring radiation surveillance, and any other special health and safety requirements. The portion of health safety which is an audit function is not funded by construction and need not be included in the estimate.
- (2) The estimate for all project administration functions is largely a function of the duration of the project from the start of Title I through completion of construction.

CHAPTER 6

COST CODES FOR CONSTRUCTION PROJECTS

1. GENERAL.

- a. The need for a common code of cost accounts has long been recognized within the Department of Energy. After the Cost Estimating Seminar in 1979, the Independent Cost Estimating (ICE) Staff worked with the Operations Offices and their supporting contractors to develop a "common" code of accounts.

During the development of the code of accounts, some of the Operations Office representatives stated they believed they had unique cost estimating situations which required the application of different formats. For example, the CSI format, used by one office, works well for homebuilding, although it does poorly for large industrial construction. The format used by another office works well for nuclear projects, but currently cannot easily accommodate synthetic fuel projects. One office has totally integrated and is using (quite successfully) the code developed by the Committee. It does not appear feasible to develop a single, detailed (below level 2) code of accounts which can accommodate all preferences within the Department at this time. However, as a beginning, the code illustrated in this chapter probably can accommodate everyone's needs through level 2. If required, the older ERDA accounts or CSI could be used below level 2. Shown in this chapter is (a) a format that prescribes uniform cost codes through level 2, but leaves open the codes to be used below level 2; and, (b) a structure showing how the cost code system feeds into the work breakdown structure. This structure provides:

- o A framework for basic uniformity in estimating and accounting for the costs of DOE construction work.
- o A means for detecting omission and duplication of items in budget estimates.
- o A basis for comparing the cost of similar work in different projects or at different locations.
- o A record of actual costs incurred on completed projects in a form that will be useful in the preparation of estimates for other projects.
- o A means of establishing the cost of property record units for continuing property accounting records.

It is envisioned that the structure presented herein will continue to evolve in the future in response to new cost estimating requirements. Nevertheless, it now appears to provide a workable structure and the update needed for the DOE Master Classification of Construction Accounts.

- b. It is essential that a cost code system be provided for use in management, estimating, and cost control purposes on a consistent basis throughout the life of each project. In order to meet this objective, itemized cost estimates and cost accounting data must be in sufficient detail to assure the reliability of such cost estimates and cost data. However, in light of fact that the Department does not now require a specific code of accounts for use in cost estimating, it is envisioned that each Operations Office will specifically delineate that code of accounts which is to be used in developing cost estimates. It is recommended that users of this cost guide (which are not required by a local Operations Office directive to use a specific code of accounts) use the cost code delineated herein.
- c. The ICE Staff has already initiated a significant effort which will lead to the establishment of a data base of cost information. The data base will be structured in accordance with the cost code described herein. An explanation of the emerging DOE Common Cost Code, which was developed jointly by the ICE Staff and DOE Operations Offices, is set forth in this paragraph. The introductory explanations present a sufficiently general "road map" to be able to be applied to any cost code and are provided to assist in understanding and applying the system.

2. PURPOSE OF A CODE OF ACCOUNTS.

A cost code system is used to control and monitor costs and to provide a basis for financial and resources planning. It will be utilized for the duration of the project. Cost estimates for construction projects essentially originate with engineering data from both internal and external sources. The internal cost data is furnished by the project participants, particularly engineering and accounting groups. External estimating data may be obtained from manufacturers of equipment, labor wage rate

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statistics, etc. The cost estimate is assembled from items and categories most likely designated by systems or engineering technical disciplines. The cost estimate is compiled in this manner prior to the start of the construction project. The purpose is to define the scope of the dollars and resources commitment for the project. For the conceptual design cost estimate, the estimate will be prepared in accordance with a project cost code system, and all future estimates will be prepared on this same basis. When work starts under the project, cost data will be accumulated and reported in accordance with this system to provide consistency between estimates and actual cost data for cost control purposes.

3. FUNDAMENTAL STRUCTURE OF A COST CODE SYSTEM.

A cost code system subdivides costs into two basic categories--direct and indirect construction costs.

Direct costs are those costs which can be defined, categorized, identified and applied specifically and directly to a cost category in a code of accounts.

Indirect costs are those costs which cannot be specifically and directly defined, categorized, identified and applied to a specific cost category; or one which can best be controlled as indirect; or a cost which does not warrant distribution to a specific direct account.

4. INTERFACE BETWEEN PROJECT WORK BREAKDOWN STRUCTURE AND COST CODE OF ACCOUNTS.

- a. During that period of a facility's life from an idea to a completed project ready to perform a needed function, a number of diverse financial activities must take place. These activities include cost estimating, budgeting, accounting, reporting, controlling and auditing. A work breakdown structure establishes a common frame of reference for relating construction activities and related costs at the summary level of detail. An example of a typical project summary work breakdown structure is shown at figure 1.
- b. The first prerequisite to the preparation of the Project Summary Work Breakdown Structure (PSWBS) is the clear understanding and statement of the project objective, the delivery of a specific major end item or end product. Once this overall project objective is established, it assists in determination of project subobjectives. These subobjectives interact to support the overall project objective in the same manner that subsystems support a total system capability. DOE project management should identify subobjectives by careful analysis of the overall project objective. This process of identification and definition of subobjectives assists in structuring the contributing elements during WBS preparation.
- c. Early in project planning, DOE project management should select the Summary WBS(s) that will best assist in preparing the preliminary PSWBS. The SWBS elements should be used as guides and may be added to, deleted, or changed as required to reflect the unique needs of the particular project.
- d. The PSWBS should be used to identify work for proposed supporting contracts. The preliminary PSWBS is based on the overall project objective and subobjectives and is prepared with the aid of a tailored Summary WBS. Normally, the PSWBS contains the top three levels only. Lower level elements may be included when necessary to clearly communicate all project requirements.
- e. Care should be taken to assure that the PSWBS represents common identification and definitional needs of the various functions involved with project management (i.e., construction, procurement, engineering, project control, etc.), since the PSWBS is used to specify contract work supporting the project. Subsequently, the PSWBS elements assigned to contractors are extended by the contractors to derive each Contract WBS (CWBS). Together, the PSWBS and each CWBS constitute the Project WBS which then provides the framework for cost, schedule and technical planning and control through the life of the project.
- f. The WBS development process is iterative. The preliminary PSWBS is not intended to be rigid and may be revised. Changes may occur when it is determined that the work effort can be more accurately defined or that a revised approach (e.g., technically different or more cost effective), should be taken to satisfy or meet the project objective. Also, contractors, while developing their CWBS, may propose to DOE alternative approaches to better accomplish the contract objectives. If the alternatives are accepted by DOE project management, the preliminary PSWBS will be revised accordingly.
- g. A plot plan of a project is illustrated at figure 2. This plot plan depicts a project as it would look at completion. Overlaid on the plot plan are the various level 1 cost code accounts that would be used in estimating the costs of this project.

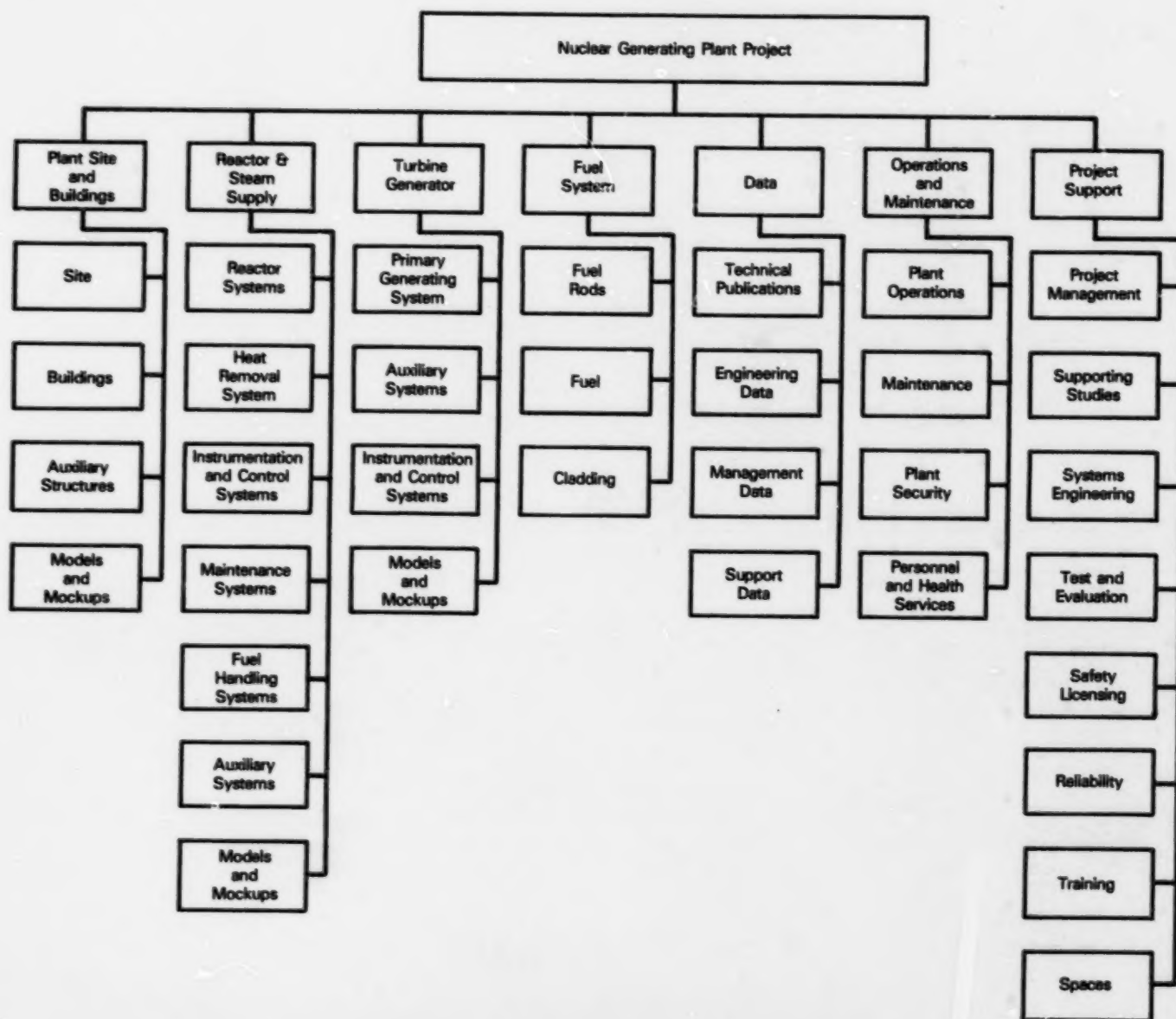


Figure 1. Typical Project Summary Work Breakdown Structure for a Nuclear Generating Plant Project

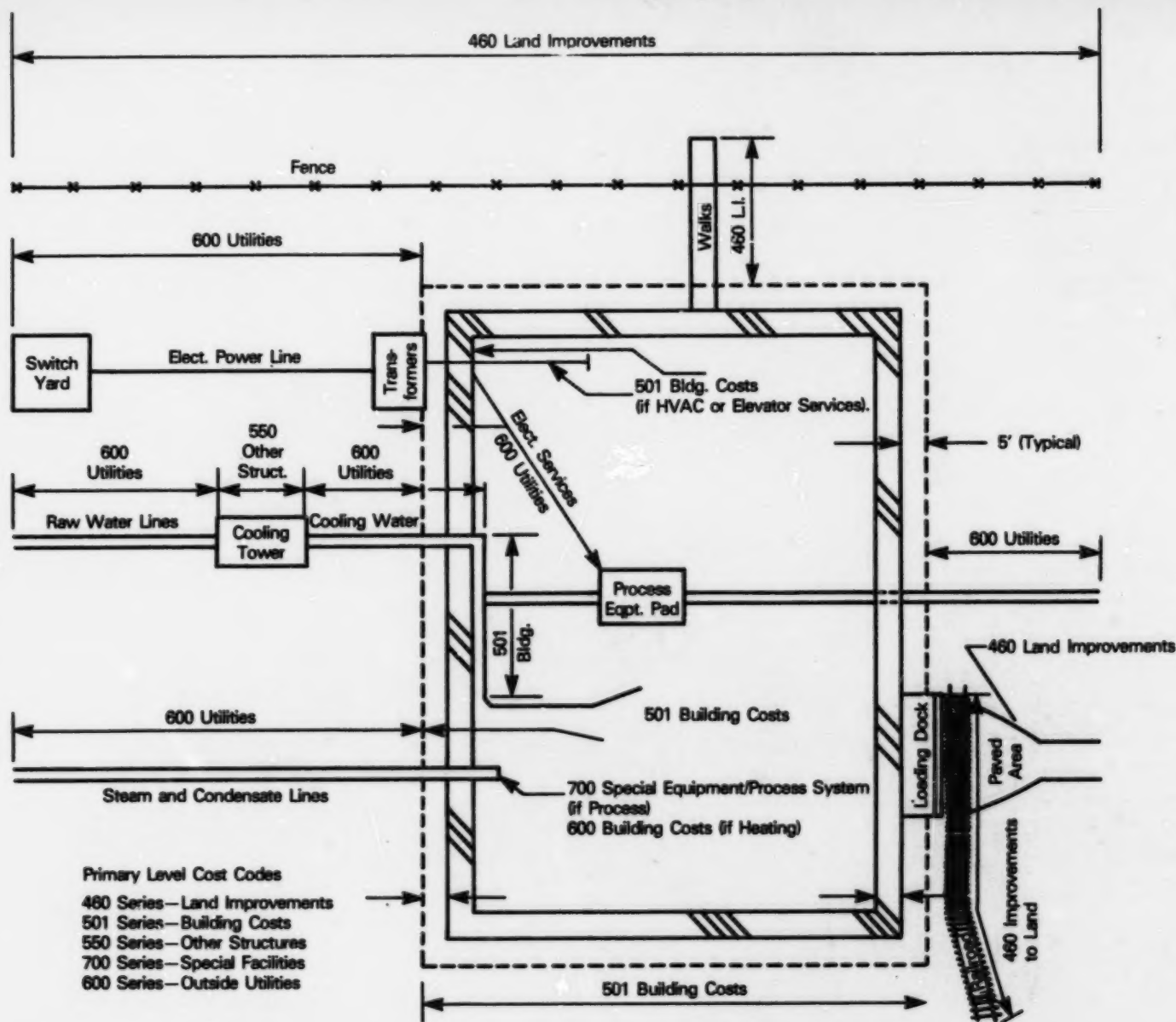


Figure 2. Typical Primary Level Cost Codes

- h. The functional linkage between the primary work breakdown structure and the code of accounts is illustrated at figure 3. After describing the direct cost categories, a recommended format will be presented which links the cost codes with the work breakdown structure.

5. INTERFACE BETWEEN ASSET TYPES AND CODE OF ACCOUNTS.

When a construction project has been completed an asset has been created and must be picked up on DOE's property book. The Accounting Practices and Procedures Handbook contains a listing of the asset types currently being used by DOE. In an effort to bridge the gap between a construction account and an asset type, the committee to update the code of accounts decided to use a primary level of accounts that coincided with the asset types used by the Finance and Accounting Offices and thereby reduce the likelihood of introducing error which could result from translating "as built" costs to asset type categories. Thus, the numbers are different from those used in the older ERDA manuals and, of course, different from the Construction Specification Institute Code. It should be noted that although the numbering is different, the elements of the emerging code of accounts permit both the older ERDA classification system and CSI system to be applied at sublevels of the cost code.

6. GENERAL DESCRIPTION OF DIRECT COSTS CATEGORIES.

- a. A direct cost system generally includes three levels of codes. The "First Level" codes, sometimes called "Primary Levels," represent the major cost categories. The major components or categories of construction work for each of the Primary Levels on each project are listed and assigned a "Second Level" or sub-summary code. These "Second Level" codes are then broken down by construction work elements or bills of material and each work element or bill of material (BM) is assigned a "Third Level" or fine detail level. The cost estimate will list the labor and material required at the "Third Level" code, then all "Third Level" codes will be summarized by their respective "Second Level" codes. Likewise all "Second Level" codes will be summarized by their respective "Primary Levels." The "Primary Levels" will be summarized by each "Subproject" or "Project" total to obtain the "Project" overall cost estimate.

- b. The Primary Level cost codes in the emerging common cost code of accounts are as follows:

<u>Level 1 Code</u>	<u>Asset Type Number</u>
Land and Land Rights	N/A
Improvements to Land	460
Buildings	501
Other Structures	550
Utilities	600
Special Equipment/Process Systems	700
Improvements for Others	800
Demolition	810
Tunneling	820
Drilling	830
Standard Equipment	N/A

Although each Primary Level cost code is listed and detailed in this chapter, a brief description of each is provided below:

- (1) Land and Land Rights. Includes the purchase price, other acquisition costs, and removal costs less salvage realized in disposing of any facilities acquired with the land. Some specific items are as follows:
- (a) Includes the costs of rights, interests, and privileges relating to land such as leaseholds, easements, rights-of-way, water and waterpower rights, diversion rights, and submersion rights.
 - (b) Includes the cost and appraised value of timber and pulpwood; cost of reforestation program for the purpose of dust and soil erosion control, retention of water tables, etc.; cost of development and improvement of timber stand; and other forestry management costs.
 - (c) Includes the cost of mineral rights and land containing mineral deposits owned by the Government.
- (2) Improvements to Land. Includes the cost of general site clearing, grading, drainage, and facilities common to the project as a whole (such as roads, walks, paved areas, fences, guard

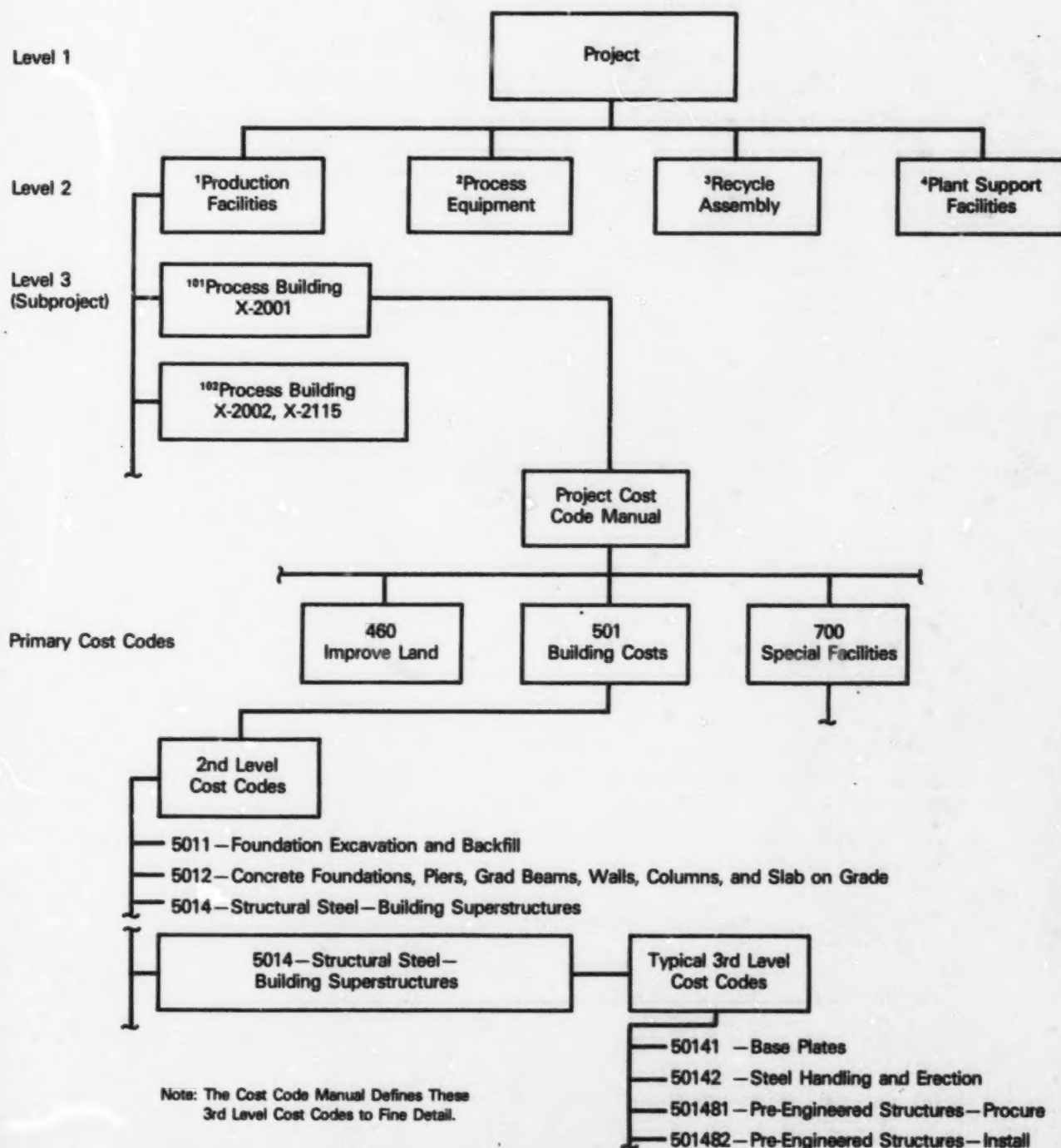


Figure 3. Interface Between Project Summary Work Breakdown Structure and Construction Cost Code

towers, railroads, port facilities, etc.), but excludes individual buildings, other structures, utilities, special equipment/process systems, and demolition, tunneling and drilling when a significant intermediate or end product of the project.

- (3) Buildings. Includes the installed cost of buildings and permanently attached appurtenances, such as fire protection, lighting, plumbing, heating, ventilation, and built-in air conditioning systems (excluding window or console air conditioning units that require no ductwork or cooling towers); and the cost of piping, conduit, and cable permanently attached to and made a part of the building. The division between building costs and the costs of utility systems is generally to be made at a point nominally five feet outside the building wall.
- (4) Other Structures. Includes the installed cost of such structures as dams, retention basins, reservoirs, swimming pools, pits, platforms, underground oil storage reservoirs, and stacks (when not a part of a building), and installed cost of structures and frames used to support such items as heat exchangers, vessels, etc., or special structures such as towers, utilidors, etc., whether inside or outside a building.
- (5) Utilities. Includes the installed cost of systems which service the project as a whole and generally extend between individual buildings or process units. Examples include communications systems, electric transmission and distribution systems, alarm systems, gas transmission and distribution systems, irrigation systems, sewerage systems, steam generation and distribution systems, water supply, pumping, treatment and distribution systems, and oil piping and distribution systems.
- (6) Special Equipment/Process Systems. Includes the installed cost of large items of special equipment and process systems such as vessels (e.g., towers, reactors, storage tanks), heat transfer (e.g., heat exchangers, stacks, cooling towers, desuperheaters, etc.), package units (e.g., waste treatment packages, clarifier packages, sulfurization, demineralization, etc.), and process piping systems.
- (7) Improvements for Others. Includes the cost of improvements made by DOE to land, buildings, structures, building services, and utility systems not owned by DOE. Plants, laboratories, and similar facilities constructed by DOE on land owned by others are not to be classified in this category.
- (8) Demolition. Includes the cost of wrecking; dismantling; cutting; drilling; and removing existing structures, equipment, and materials; as well as any excavation required to facilitate demolition and the cleaning, stacking, loading, hauling, and unloading of material for salvage and/or disposal when such activity represents a major activity in accomplishment of the project. Minor, routine demolition will be listed under improvements to land.
- (9) Tunneling. Includes the complete costs of constructing a tunnel to include excavation, drilling, blasting, mucking, shoring, timbering, bolting, mechanical utilities (air, water, and vent lines), surface construction, installation (shaft collars, portal facings, retaining walls, rock, bolts, fences, gates, hatches, doors, muck dumping facilities, anchors, guys, deadmen, buildings, foundations, docks, etc.), and associated mobilization and demobilization.
- (10) Drilling. Includes the complete cost of drilling to include purchase or lease of the drilling rig associated material mandrels, jet subs, drill collars, drill pipe, kellys, goosenecks, casing, detergent, mud additives and other chemicals, tool repair, installing casing (double jointing, lugging, cutting lifting eyes, belling, and installing guidelines), installing the drilling rig, correcting problems (plugback to correct well bore deviations), cleaning out and conditioning the hole, coring, sidewall, sampling, dewatering, fishing, laboratory support, building support structures, and safety fences.
- (11) Standard Equipment. This level includes items of equipment in which only a minimum of design work is required, such as "off-the-shelf" items. Examples of standard equipment include office furniture, laboratory equipment, heavy mobile equipment, etc. Items of standard equipment that are incorporated into Second Level code systems will be included with that system and not under standard equipment.

Subproject Designation. Subproject is a term used to divide a project into separately manageable portions of the project. A subproject is generally used to identify each separately capitalizable identity, such as a building. A subproject can also be used to identify a specific geographical area or separate physical features of a project. A matrix should be drawn for each project listing the subprojects designated and indicating all the Second Level cost codes for the construction work required by each. A project cost code manual must be provided for each line item construction project. Additional cost codes may be used and defined as required when none are listed in this

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section to define the construction work required. If the cost code system has not been developed prior to the conceptual design report (CDR), it must be issued as a part of the CDR. All subsequent estimates must then be made in accordance with the cost code system.

7. LIST OF DIRECT CONSTRUCTION COST CODES.

- a. The following cost codes constitute the Primary and Second Level cost codes for use on the direct construction costs. Any reasonable breakdown of these cost codes is permissible as long as they can be summarized to the cost codes shown and the definitions given.
- b. Direct costs are those costs which can be identified with specific physical features of a project. These costs are identified at the Second Level cost code only, and the Third Level or fine detail is not carried in the accounting systems. The cost estimate sheets may use single digit sequential listings of the fine detail of the Third Level items comprising each Second Level cost code. A listing of Primary and Secondary Cost Codes is as follows:

<u>Primary Level</u>	<u>Secondary Level</u>	
N/A		<u>Land and Land Rights</u>
401		Land
410		Land Rights
430		Minerals
440		Timber
460		<u>Improvements to Land</u>
	4601	Site Preparation
	4602	Drainage
	4603	Landscaping
	4605	Railroads
	4606	Port Facilities
	4700	Roads, Walks and Paved Areas
	4800	Fences and Guard Towers
	4900	Other Improvements to Land
501		<u>Buildings</u>
	5011	Excavation and Backfill
	5012	Concrete
	5013	Masonry
	5014	Metals
	5015	Wood and Plastic
	5016	Finishes
	5017	Special Construction
	5018	Mechanical
	5019	Electrical
550		<u>Other Structures</u>
	5501	Excavation and Backfill
	5502	Concrete
	5503	Masonry
	5504	Metals
	5505	Wood and Plastic
	5506	Thermal and Moisture Protection
	5507	Special Construction
	5508	Mechanical
	5509	Electrical
600		<u>Utilities</u>
	6100	Communications Systems
	6150	Electric Transmission and Distribution Systems
	6200	Alarm Systems
	6250	Gas Transmission and Distribution Systems
	6300	Irrigation Systems
	6400	Sewerage Systems
	6450	Steam Generation and Distribution Systems
	6500	Water Supply, Pumping, Treatment and Distribution Systems
	6600	Oil Piping and Distribution Systems
	6900	Other Utilities

<u>Primary Level</u>	<u>Secondary Level</u>	<u>Special Equipment/Process Systems</u>
700	7010	Vessels
	7020	Heat Transfer
	7030	Mechanical Equipment
	7040	Package Units
	7050	Process Piping
	7060	Electrical
	7070	Protective Cover
	7080	Reactor Components
800		Improvements for Others
810		Demolition
820		Tunneling
830		Drilling
N/A		Standard Equipment
710		Heavy Mobile Equipment
715		Hospital and Medical Equipment
720		Laboratory Equipment
725		Motor Vehicles and Aircraft
730		Office Furniture and Equipment
735		Process Equipment (for Mfr.)
740		Railroad Rolling Stock
745		Reactors and Accelerators
750		Portable Security and Protection Equipment
755		Shop Equipment
760		Reserve Construction Equipment Pool
770		ADP Equipment
799		Miscellaneous Equipment

8. THIRD LEVEL ACCOUNTS.

Accounts below Level Two have been deliberately omitted from the code of accounts illustrated herein because it is likely that the older ERDA accounts or CSI would be used. Additionally, flexibility must be inherent in a manual of this type to permit users to have the option of using different detailed accounts. Noteworthy is the fact that the Level Two accounts under buildings (501) and other structures (550) correspond to divisions under the CSI code; while the other Level Two codes designate assets which could be structured using either CSI or ERDA cost codes at Level Three and below.

9. COST ESTIMATE MATRIX STRUCTURE.

Figure 4 illustrates the code structured in a detailed matrix for construction. The row headings correspond to the first and second level accounts described above. The column headings (designated areas) correspond to the WBS discussed in paragraph 4. These elements are not specified because they must necessarily be different for each new construction project. It is believed that these headings would correspond to Level Two or Three of the Project Summary WBS. Indirect costs may be allocated against direct construction accounts or may be treated as a separate identifiable cost account. In any event, the indirect costs must be allocated to direct cost accounts before the project is picked up on the DOE Property Book.

10. COST ESTIMATE SUMMARY SHEET.

Figure 5 illustrates a cost estimate summary sheet which collects total project costs. A detailed explanation of the direct construction accounts previously identified as well as all of the cost accounts shown on the summary sheet are defined in the cost code of accounts which follows.

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CONSTRUCTION COSTS

(TO BE DETERMINED BY PROJECT MANAGER)

CATEGORY	AREA 1	AREA 2	AREA 3	AREA 4	AREA 5	AREA 6	AREA 7	TOTAL
460 Improvements to Land								
4601 Site Preparation								
4602 Drainage								
4603 Landscaping								
4605 Railroads								
4606 Port Facilities								
4700 Roads, Walks & Paved Areas								
4800 Fences & Guard Towers								
4900 Other Improvements to Land								
Subtotal								
501 Buildings								
5011 Excavation & Backfill								
5012 Concrete								
5013 Masonry								
5014 Metals								
5015 Wood & Plastic								
5016 Finishes								
5017 Special Construction								
5018 Mechanical								
5019 Electrical								
Subtotal								
550 Other Structures								
5501 Excavation & Backfill								
5502 Concrete								
5503 Masonry								
5504 Metals								
5505 Wood & Plastic								
5506 Thermal & Moisture Protection								
5507 Special Construction								
5508 Mechanical								
5509 Electrical								
Subtotal								

Figure 4

CONSTRUCTION COSTS

(TO BE DETERMINED BY PROJECT MANAGER)

CATEGORY	AREA 1	AREA 2	AREA 3	AREA 4	AREA 5	AREA 6	AREA 7	TOTAL
600 Utilities								
6100 Communications Systems								
6150 Elec. Trans. & Dist. Systems								
6210 Alarm Systems								
6250 Gas Trans. & Dist. Systems								
6300 Irrigation Systems								
6400 Sewerage Systems								
6450 Steam Gen. & Dist. System								
6500 Water Supply, Pumping Treat. & Dist. Sys.								
6600 Oil Pipe & Dist. System								
6900 Other Utilities								
Subtotal								
700 Special Equipment/Process Systems								
7010 Vessels								
7020 Heat Transfer								
7030 Mechanical Equipment								
7040 Package Units								
7050 Piping								
7060 Electrical								
7065 Instrumentation								
7070 Protective Cover								
7080 Reactor Components								
Subtotal								
800 Improvements for Others								
810 Demolition								
820 Tunneling								
830 Drilling								
*** Total Direct Costs ***								
*** Total Indirect Costs ***								
***** Total *****								

Figure 4 (continued)

COST ESTIMATE SUMMARY SHEET

PROJECT: _____

I. ENGINEERING

A. Design Engineering	\$ _____	
B. Inspection/Design Validation Engineering	\$ _____	\$ _____

II. LAND & LAND RIGHTS

401 Land	\$ _____	
410 Land Rights	\$ _____	
430 Minerals	\$ _____	
440 Timber	\$ _____	\$ _____

III. CONSTRUCTION (See Figure 4)

IV. STANDARD EQUIPMENT

710 Heavy Mobile Equipment	\$ _____	
715 Hospital & Medical Equipment	\$ _____	
720 Laboratory Equipment	\$ _____	
725 Motor Vehicles & Aircraft	\$ _____	
730 Office Furniture & Equipment	\$ _____	
735 Process Equipment (for Mfr.)	\$ _____	
740 Railroad Rolling Stock	\$ _____	
745 Reactors & Accelerators	\$ _____	
750 Portable Security & Protection Equipment	\$ _____	
755 Shop Equipment	\$ _____	
760 Reserve Construction Equip. Pool	\$ _____	
770 ADP Equipment	\$ _____	
799 Misc. Equipment	\$ _____	\$ _____

V. INDIRECT COSTS

\$ _____

VI. CONTINGENCY

\$ _____

VII. ESCALATION

\$ _____

TOTAL \$ _____

Figure 5

COMMON CODE OF COST ACCOUNTS

U.S. DEPARTMENT OF ENERGY

1. ENGINEERING.

a. DESIGN ENGINEERING.

(1) OBJECTIVES:

Design engineering objectives shall be (1) achieving minimum construction costs consistent with programmatic, environmental, security, and safety requirements; (2) achieving technical adequacy; (3) achieving optimum economy in operation and maintenance; and (4) assuring that appropriate consideration is given to the expected period of use, sound construction practices, quality assurance requirements, energy conservation requirements, decontamination and decommissioning requirements, and the appearance of completed facilities. Trade-off studies are an essential element of the design effort required to achieve these objectives.

(2) DESIGN ENGINEERING WILL INCLUDE THE FOLLOWING:

- (a) Conducting or arranging for and supervising all necessary topographical and other field surveys, the preparation of maps, and necessary test borings and other subsurface investigations.
- (b) Consulting and collaborating with the U.S. Department of Energy (DOE) or its designees to determine the requirements which will govern design of the project and establishing architectural and engineering criteria for such design.
- (c) Conducting preliminary studies; preparing preliminary sketches, drawings, layout plans, outline specifications, and reports showing features and characteristics of the design proposed to meet the requirements, including applicable codes and standards and quality assurance levels; and coordinating, with the assistance of the operating contractor, utility services requirements with the supplying utility companies.
- (d) Preparing preliminary estimates of cost and time schedules for (1) completion of the design and working drawings and specifications; (2) procurement; and (3) construction.
- (e) Preparing preliminary estimates of labor, material, and equipment quantities, identifying long-lead procurements or other potential supply problems.
- (f) Undertaking restudy and redesigning work due to changes required by DOE from the review of preliminary design.
- (g) Preparing working drawings and specifications for construction; contracting bidding documents for the approval of DOE; and coordinating, with the assistance of the operating contractor, final utility services requirements with the supplying utility companies.
- (h) Preparing or participating with others in the preparation of a detailed estimate of the cost of construction based on the approved design and working drawings and specifications; and preparing estimated construction schedules, including procurements.
- (i) Assisting DOE and its designees in securing, analyzing, and evaluating proposals and bids for materials, equipment, and services required for construction.

b. INSPECTION/DESIGN VALIDATION ENGINEERING.

(1) OBJECTIVES:

Inspection/design validation engineering objectives shall be (1) determining overall compliance with contract drawings and specifications; (2) ascertaining that workmanship and kind and quality of materials conform to contract specifications; (3) ensuring that final drawings reflect the "as built" condition of the project; (4) testing the operating equipment and systems prior to final acceptance; and (5) serving as a basis for determining the adequacy of the design. Inspection and testing are essential elements of the validation effort required to achieve these objectives.

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(2) INSPECTION/DESIGN VALIDATION ENGINEERING WILL INCLUDE THE FOLLOWING:

- (a) Furnishing and maintaining governing lines and benchmarks to provide horizontal and vertical controls to which construction may be referred.
- (b) Checking and approving, or requiring revision of, all vendors' shop drawings to assure conformity with the approved design and working drawings and specifications.
- (c) Inspecting the execution of construction so as to assure adherence to approved drawings and specifications.
- (d) Inspecting construction workmanship, materials, and equipment; and reporting on their conformity or nonconformity to the approved drawings and specifications.
- (e) Making or procuring such field or laboratory tests of construction workmanship, materials, and equipment, as may be required.
- (f) Preparing estimates of reasonable amounts of increase or decrease in contract price and/or contract completion term for contract modifications, evaluating proposals submitted by the construction contractor for such contract adjustments, and making recommendations for use in negotiating.
- (g) Preparing reports and making recommendations on status of deliveries of materials and equipment, as may be required.
- (h) Preparing monthly and other reports of the progress of construction, as may be required, and partial, interim, and final estimates and reports of quantities and values of construction work performed for payment or other purposes.
- (i) Furnishing reproducible, "as built" record drawings and marked-up specifications showing construction as actually accomplished.

2. LAND AND LAND RIGHTS.

a. 401 LAND.

Includes the purchase price, other acquisition costs, and removal costs less salvage realized in disposing of any facilities acquired with the land. Some specific items are as follows:

(1) COST OF LAND:

Includes costs incurred in acquiring land, such as purchase price, amounts paid other Federal agencies, and other acquisition costs.

(2) REMOVAL OF EXISTING STRUCTURES:

Includes cost of labor and materials for demolition and removal of buildings and other structures, acquired with the purchase or acquisition of the site, that are not usable.

(3) COST RECOVERIES:

Includes the amounts received from cash sale of net transfer values of buildings and other structures, acquired with the purchase or acquisition of the site, on which disposal is made.

(4) RELOCATING HIGHWAYS AND HIGHWAY BRIDGES:

Includes all costs required in relocation of highways made necessary by construction of the project.

(5) RELOCATION OF RAILROADS AND RAILROAD BRIDGES:

Includes relocation of railroads made necessary by construction of the project.

(6) RELOCATION OF PUBLIC UTILITIES:

Includes relocation and protection of public utility properties such as electrical, communications, water, etc.

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(7) CEMETERIES:

Includes disinterment, transportation, and reinterment of remains.

(8) FAMILIES:

Includes removal and relocation of displaced families.

(9) MUNICIPAL FACILITIES:

Includes relocating and protecting sewage systems, water systems, streets, and other municipal facilities.

(10) INDUSTRIAL:

Includes relocating and protecting industrial facilities.

(11) OTHER STRUCTURES AND IMPROVEMENTS:

Includes relocating and protecting buildings and improvements not elsewhere provided for in the cost codes.

b. 410 LAND RIGHTS.

Includes the costs of rights, interests, and privileges relating to land such as leaseholds, easements, rights-of-way, water and waterpower rights, diversion rights, and submersion rights.

c. 430 MINERALS.

Includes the cost of mineral rights and land containing mineral deposits owned by the Government.

d. 440 TIMBER.

Includes the cost and appraised value of timber and pulpwood; cost of reforestation program for the purpose of dust and soil erosion control, retention of water tables, etc.; cost of development and improvement of timber stand; and other forestry management costs.

3. CONSTRUCTION.

a. 460 IMPROVEMENTS TO LAND.

Includes the cost of general site clearing, grading, drainage, and facilities common to the project as a whole (such as roads, walks, paved areas, fences, guard towers, railroads, port facilities, etc.), but excludes individual buildings, other structures, utilities, special equipment/process systems, and demolition, tunneling and drilling when a significant intermediate or end product of the project.

(1) 4601 SITE PREPARATION.

(a) Includes labor and material required for surveying and mapping, subsurface investigating, clearing, excavating, and backfilling to bring area to a general grade. This cost code includes digging test trenches required during construction, demolition, disposing of surplus materials, maintaining spoil areas, and related work.

(b) Excludes specific grading and base materials for roads, walks, drives, and parking areas; and grading for culverts and culverts headwalls; final grading (see Landscaping); grading for railroads; and marginal and drainage ditches which are included in other accounts.

(c) Some specific examples of items included in this account are as follows:

(1) CLEARING, GRADING, AND BACKFILL:

Includes cost for clearing, digging test trenches, and grubbing required during construction machine and hand excavation; backfilling and compacting of earth and stone either by hand or by mechanical and pneumatic equipment; disposing of surplus materials; and maintaining spoil areas; and related work. This cost code does not include specific grading or base materials for roads, drainage ditches, etc. (see second level cost code description).

(2) PUMPING AND DEWATERING:

Includes cost for handling, installation, operation, and removal of pumps and appurtenances required for dewatering of areas.

(3) SUBSURFACE INVESTIGATION:

Includes labor and material costs associated with subsurface investigations to include borings, core drilling, standard penetration tests, seismic explorations, testing, analysis, laboratory reports, etc.

(4) SURVEYS AND MAPPING:

Includes all costs incurred in connection with locating, marking or otherwise identifying areas within or about the construction site.

(5) DEMOLITION:

Includes cost for demolition of existing on-site facilities to facilitate clearing of the site.

(6) BORE HOLES:

Includes labor and material required to physically locate, identify, backfill, plug, compact, fine grade, landscape, and test any existing bore holes.

(2) 4602 DRAINAGE.

- (a) Includes labor and material required for the installation of all storm sewers and drains for the area between points five feet outside the building lines. This cost code includes all work for storm sewer manholes; headwalls; precast, concrete slabs; cast-in-place concrete; street storm water receivers and outfall drainage ditches; and all drainage in the switchyard.
- (b) Excludes culverts and marginal ditches along roads, paved areas, railroads, and cooling ponds or sewage lagoons.
- (c) Specific elements of this account are:

(1) INSTALLED EQUIPMENT:

Includes cost of labor, material, and installed equipment that is applicable to the work described in the second number account. Cost of equipment includes invoice price and transportation when charged direct. Costs for each size and type of equipment included in this cost code should be readily identifiable in the cost code or supporting records.

(2) EXCAVATION AND BACKFILL:

Includes cost required for excavation shoring, backfilling, and removal of surplus material for subsurface piping, manholes, ditches, and catch basins, from a point five feet outside the building line. It excludes culverts and marginal ditches along roads, paved areas, and railroads (see second level cost code description). It includes all rip-rap work for storm ditches.

(3) CATCH BASINS AND MANHOLES:

Includes cost required for forming, hauling, reinforcing, placing, curing, protecting, and finishing of concrete for manholes, catch basins, headwalls, and drainage ditch slabs. It includes all rip-rap work for storm ditches.

(4) PIPING:

Includes cost required for installation of cast iron pipe, corrugated metal tile, and concrete pipe for the storm sewer system, from a point five feet outside the building line.

(3) 4603 LANDSCAPING.

Includes labor and material for final grading and landscaping the area. This cost code includes applying or planting such items as topsoil, fertilizer, seeds, seedlings, sod, and shrubs.

(a) FINAL GRADING:

Includes cost for bringing the area surface to its final elevation.

(b) LANDSCAPING:

Includes cost for applying or planting topsoil, fertilizer, seeds, seedlings, sod, shrubs, and other similar items.

(4) 4605 RAILROADS.

(a) Includes labor and material required for installing railroad trackage outside of building limits. This cost code includes excavation; backfill; compacting; fine grading; setting of ties and rails; hauling and spreading of ballast, construction related culverts, bridges, and headwalls; and installing warning systems and guard gates.

(b) Excludes railroad cars, engines, and other railroad equipment that will operate on the track.

(c) Some specific examples of items included in this account are as follows:

(1) INSTALLED EQUIPMENT:

Includes cost of labor and materials and installed equipment that is applicable to the work described in this cost code. Cost of equipment includes invoice price and transportation when charged direct. Costs for each size and type of equipment included in this cost code should be readily identifiable in the cost code or supporting records.

(2) EXCAVATION:

Includes cost for preparing roadbed for trackage. It includes excavating, backfilling, compacting, fine grading, and marginal ditches.

(3) TRACK LAYING AND SURFACING:

Includes cost for hauling and placing ties, rails, ballast, and other track materials such as angle bars, frogs, guardrails, track bolts and nuts, rail joints, switches, spikes, and related work.

(4) SPECIAL DRAINAGE STRUCTURES:

Includes cost for excavating, hauling, and placing drain pipe. It includes forming, reinforcing steel and concrete required for culverts, bridges, and headwalls.

(5) WARNING SYSTEMS AND GATES:

Includes cost for the complete installation of railroad warning systems and gates.

(5) 4606 PORT FACILITIES.

(a) Includes labor and material required for constructing a port facility. This cost code includes excavation, backfill, compacting, and construction involved in building docks, piers, levies, jetties, anchorages, and other parts of a port facility.

(b) Some specific examples of items included in this account are as follows:

(1) INSTALLED EQUIPMENT:

Includes cost of labor, materials, and installed equipment that is applicable to the work described in this cost code. Cost of equipment includes invoice price and transportation charge when direct.

(2) EROSION CONTROL:

Includes cost of preparing retaining walls, levies, jetties, etc. Includes excavating, backfilling, compacting, and construction materials (to include forms and rockfill).

(3) PIERS:

Includes installed cost of concrete or timber pier to include any track or road surface which runs along its length.

(4) BUOYS AND WARNING SYSTEMS:

Includes the installed cost of channel buoys, warning buoys, warning lights, horns, whistles, and other safety devices or systems.

(6) 4700 ROADS, WALKS, AND PAVED AREAS.

(a) Includes labor and material required for the stripping, grading, backfilling, compacting, and application of base and surface materials for permanent roads, walks, and paved areas. It includes bridges, culverts and culvert headwalls over drainage areas; grading of road and marginal ditches; construction and painting of curbs and fabricating or installing guardrails, traffic barriers, and incidental appurtenances and stripping.

(b) Excludes any work for railroad track and grade crossings (see Railroads).

(c) Elements to be included are:

(1) EXCAVATION, GRADING, AND BACKFILL:

Includes cost for machine and land excavation, stripping, grading, backfill, and disposal of surplus materials.

(2) SURFACING:

Includes cost for hauling; placing; treating; compacting macadam, asphalt, concrete, and other wearing surfaces; and stripping.

(3) DRAINAGE STRUCTURES AND BRIDGES:

Includes cost for installing drains, culverts, and bridges over drainage areas and grade crossings. It includes all concrete and related items.

(4) GUARD RAILS, POSTS, AND TRAFFIC BARRIERS:

Includes cost for all work to fabricate and install protective barriers and necessary stripping.

(5) CURBS:

Includes cost of installing curbs and painting.

(7) 4800 FENCES AND GUARD TOWERS.

(a) Includes labor and material required for security fences and gates for the area and all work for erecting guard towers and gatehouses, complete with interior electrical work.

(b) Excludes floodlights and exterior electrical work (see Utilities).

(c) Elements to be included are:

(1) SECURITY FENCES:

Includes cost for handling, hauling, excavating, erecting, aligning, and other work to install fence posts, fabric, and all necessary gates, including grounding and electric gate operators.

(2) GATEHOUSES AND GUARD TOWERS:

Includes cost for complete installation of foundations and superstructures. It excludes exterior electrical work and floodlights (see Utilities).

(8) 4900 OTHER IMPROVEMENTS TO LAND.

Includes the installed cost of any improvement to land not included in codes 4601 through 4800, except demolition, tunneling, and drilling, which are listed under accounts 810, 820, and 830, respectively. Improvement to land belonging to others will be included under account 800.

b. 501 BUILDINGS.

Includes the installed cost of buildings and permanently attached appurtenances, such as fire protection, lighting, plumbing, heating, ventilation, and built-in air conditioning systems (excluding window or console air conditioning units that require no duct work or cooling towers); and the cost of piping, conduit, and cable permanently attached to and made a part of the building. The division between building costs and the costs of utility systems is generally to be made at a point nominally 5 feet outside the building wall.

(1) 5011 EXCAVATION AND BACKFILL.

(a) Includes labor and material required for building foundations, including excavation, disposal, and backfill for footings, grade beams, pads, pits, manholes, and other subsurface structures. It also includes pumping, dewatering, compacting, fine grading, and selected materials for fills.

(b) Specific elements of this account are:

(1) EXCAVATION:

Includes cost for machine and hand excavation, and disposal of surplus material.

(2) BACKFILL:

Includes cost for backfill and compacting of earth, stone, or other selected materials, either by hand or by mechanical and pneumatic equipment.

(3) PUMPING AND DEWATERING:

Includes cost for handling, installation, operations, and removal of pumps and appurtenances required for dewatering excavated areas.

(4) FINE GRADING:

Includes cost for fine grade work preparatory to ground floor slab construction, including borrow and backfill of fine grade selected materials.

(5) ROCK REMOVAL:

Includes cost of removing rock during excavation, including drilling, blasting, breaking, loading, hauling, and disposal of surplus materials.

(2) 5012 CONCRETE.

(a) This cost code covers all building concrete to include concrete on or below grade, major concrete slabs, floors above grade, equipment foundations, and miscellaneous concrete (such as thresholds, stairs, lintels, curbs, walks, etc.). Specifically, it covers labor and material required for forming, placing, and waterproofing of concrete for building foundations, piers, grade beams, walls, columns, and slabs. It includes all work in connection with related reinforcing steel, concrete encasement of structural steel columns, and any precast concrete. Includes labor and materials required for forming, placing of major concrete slabs or floors above grade, including integral beam

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construction and all work in connection with related reinforcing steel mesh. Covers labor and material required for forming and placing of foundations for building equipment, including all work in connection with related reinforcing steel, and covers labor and material required for forming and placing of concrete for items not otherwise covered above, including all work in connection with related reinforcing steel, as well as thresholds, stairways, landings, penthouse floor slabs, lintels, curbs, walks, and minor floor slabs.

- (b) This cost code excludes all work in connection with the construction of instrument tunnels, foundations for process equipment, and piping (except the embedded structure support).

- (c) Specific elements of this account are:

(1) FORMS AND SCREEDS:

Includes cost for hauling, fabricating, erecting, stripping, cleaning, and disposing of form work and screeds.

(2) CONCRETE:

Includes cost for hauling, placing, curing, finishing, protecting, and repairing of concrete.

(3) FORM TIES, KEYWAYS, INSERTS, AND JOINTS:

Includes cost for hauling, fabricating, and inserting of form ties, keyways, inserts, and premoulded expansion material.

(4) PRECAST CONCRETE:

Includes cost for hauling, handling, and placing all precast concrete items.

(5) WATERPROOFING:

Includes cost in connection with waterproofing required for concrete ground floor slab.

(6) REINFORCING STEEL AND MESH:

Includes cost of labor for handling, hauling, bending, fabricating, placing, tying, and cleaning of reinforcing steel and mesh.

(7) FLOOR HARDENER:

Includes cost of labor for cleaning of concrete slabs, preparing, and applying floor hardener.

(8) FOUNDATION DRAINS:

Includes cost of labor for installing building foundation drain piping.

(9) ANCHOR BOLTS AND SLEEVES:

Includes cost for handling, fabricating, aligning, and setting of anchor bolts for building superstructure and sleeves. This cost code excludes grouting and setting of base plates and miscellaneous structural steel and iron (see second level cost code description).

(3) 5013 MASONRY.

- (a) This cost code covers labor and material used in masonry building construction. Account includes the hauling; rehauling; handling; erecting; and setting of brick, adobe, structural glazed tile masonry, concrete unit masonry, high-lift grouted masonry, tile, terra cotta veneer, glass unit masonry, stone, simulated masonry, and refractories (such as flue liners, combustion chambers, firebrick, and castable refractory materials). Cost of mortar, aggregate anchor irons, angle iron, filler, fireproofing, furring, lintel; and costs of hauling sand, aggregate and mortar, mixing, carrying to work site, scaffolding,

and other devices required for masonry construction. Chemicals added to the mortar to include coloring and antifreeze will also be included, as well as cleanup and conditioning of the job site.

(b) Specific examples are:

(1) MASONRY:

Includes cost for hauling, handling, placing, and construction of masonry and concrete block unit walls and partitions, and related scaffolding, bracing, repairing, waterproofing, and finishing. This cost code excludes painting.

(2) FACE TILE:

Includes cost for hauling, handling, and installation of face tile, and related scaffolding, bracing, and cleaning and washing of face tile after erection.

(4) 5014 METALS.

(a) This cost code covers labor and material required for building superstructure steel, including crane rail and all members framed directly into the superstructure and purchased with the structural steel. The account includes fabrication, handling, hauling, erecting, and setting of base plates required to completely install the structural steel. This cost code will be used for procurement and erection of prefabricated, pre-engineered structures. It includes labor and material required for process pipe structural steel supports and hangers, related base plates, stair and platform stringers, gratings, handrails, valve operating platforms, ladders, structural steel door sub-bucks, filter and louver structural steel frames, trapeze hangers serving more than one item, railroad track in truck alley to the five-foot line of building, interior and exterior metal door frames, toeplates, hatch frames, wire partitions, thresholds, door and window lintels, metal sleeves in the building structure, miscellaneous iron embedded in concrete, equipment support structure at the time of placing, and other miscellaneous structural steel and iron.

(b) This cost code excludes anchor bolts for building superstructures and base plates included with process equipment.

(c) Some specific elements are:

(1) BASE PLATES:

Includes cost for handling, hauling, setting, and grouting of base plates required to completely install the structural steel. This account excludes base plates for process gas piping and those included with process equipment (see second level cost code description).

(2) STEEL HANDLING AND ERECTION:

Includes cost for handling, hauling, reloading, rehauling, shaking out, erecting, plumbing, and riveting or welding of structural steel for building superstructure.

(3) HANGERS AND SUPPORTS:

Includes cost for fabricating, handling, hauling, and installing trapeze-type hangers and supports.

(4) RAILROAD TRACK IN TRUCK ALLEY:

Includes cost for installing rail and related items such as metal ties, tie plates, and bumper blocks:

(5) STRUCTURAL STEEL:

Includes cost for handling, hauling, erecting, plumbing and bolting, riveting or welding of miscellaneous structural steel.

(6) EMBEDDED STEEL AND IRON:

Includes cost for fabricating, handling, hauling, setting, and grouting of anchor bolts and base plates required for miscellaneous structural steel and iron, including related caulking.

(7) EQUIPMENT SUPPORT STRUCTURE:

Includes cost of labor for fabricating, handling, hauling, and installing the equipment support structures.

(8) PRE-ENGINEERED STRUCTURES:

This account will be for all cost necessary for procurement of the pre-engineered, prefabricated structures.

(5) 5015 WOOD AND PLASTIC.

(a) This cost code covers labor and material required for building structural frames made of wood or plastic construction. The account includes framing and sheathing, wood decking, fiber underlayment, timber trusses, pole construction, trestles, wood treatment, and associated hardware items such as nails, screws, bolts, glue, and other fasteners. Includes wood stairs and railings and any wood used to secure, protect or, in any way, provide safety at the building site to include safety rails, safety fences, temporary ladders, temporary overhangs, or ceilings. Includes all plastic used to wrap or protect the materials exposed to the elements at the building site.

(b) Excludes wood or plastic used for earthwork and concrete forms.

(c) Some specific examples are:

(1) FRAMING AND ERECTION:

Includes cost for handling, hauling, reloading, erecting, and fastening of structural wood for the building superstructure.

(2) DECKING:

Includes cost of fabricating, handling, hauling, and installing decking.

(3) TEMPORARY SAFETY STRUCTURES:

Includes cost of fabricating, handling, hauling, and installing temporary structures made of wood which are used to protect the work site to include the digging, emplacement, and fastening of posts and poles.

(6) 5016 FINISHES.

(a) This cost includes accounts which generally fall under the broad categories of thermal and moisture protection, doors and windows, finishes and specialties. This account covers labor and material required for construction and revision of built-up roofing, including flashing, caulking, scuppers, gutters, sheet metal conductors, hatch covers, and insulation and repair of damaged roofs and roofing items. It also includes metal, precast or poured roof decks other than reinforced concrete slabs, and special expansion joints and cap flashings.

(b) This cost code excludes roofing items included with pre-engineered structures.

(c) Specifically included are:

(1) ROOF CONSTRUCTION:

Includes cost for hauling, handling, and installation of roofing, including revisions, and roof insulation.

(2) ROOF REPAIRS:

Includes cost for repairing completed or partially completed roofs that have been damaged by construction operations, high winds, or weather damage.

- (3) ROOF DECKS:
- Includes cost for installing metal, precast or poured decks other than reinforced concrete slabs, and installation of hatch covers.
- (4) EXPANSION JOINTS, FLASHINGS, AND CONDUCTORS
- Includes cost for hauling, fabrication, erection, and installation of special expansion joints and cap flashings for building roofs, scuppers, gutters, gravel stops, sheet metal conductors, and similar items.
- (5) ROOF ACCESSORIES:
- Includes cost for hauling, fabrication, erection, and installation of skylights, roof hatches, and gravity ventilators.
- (d) This account covers labor and material required for the installation of building siding, insulation, flashing, caulking, special expansion joints, and minor repairs. This cost code excludes siding items for pre-engineered structures.
- (1) SIDING:
- Includes cost for hauling, handling, and installation of building siding, insulation, and minor repairs.
- (2) EXPANSION JOINTS AND FLASHING:
- Includes cost for hauling, fabrication, erection, and installation of special expansion joints for flashing of building siding, including caulking.
- (3) INSULATION:
- Includes cost for purchasing, hauling, and installation of building insulation and fireproofing.
- (e) In addition, it covers labor and material required for construction of interior masonry walls and partitions, toilet partitions, interior plaster walls, metal-stud tile-faced partitions, and acoustical hard plaster or metal ceilings.
- (1) INTERIOR WALLS AND PARTITIONS:
- Includes costs for hauling, handling, placing, and constructing interior walls and partitions to include related scaffolding, bracing, repairing, waterproofing, fireproofing, and finishing.
- (2) CEILINGS:
- Includes cost for hauling, handling, and installation of plaster walls and plaster, metal, or other ceilings. It also includes erection of bar joists; channels; metal lathe; application of hard plaster, acoustical plaster, and metal or fibre acoustical ceiling units; installation of insulation, special moulding, and related scaffolding, patching, and repairing.
- (3) SPECIAL FLOORING:
- Includes cost for flooring other than concrete such as asphalt, rubber, koroseal, quarry tile or wood, including hauling, handling, placing, and finishing of flooring and related cover base and shoe moulds.
- (4) MILLWORK AND TRIM:
- Includes cost for hauling, handling, fabricating, and installing all millwork and wood trim. Includes studs and plates for all wood partitions.
- (5) METAL DOORS:
- Includes cost for hauling, handling, erecting, and other work to install metal and metal clad doors, complete with frames, hardware, and operating devices.

- (6) WOOD DOORS:
- Includes cost for hauling, handling, erecting, and other work to install wood doors, complete with hardware.
- (7) WINDOWS:
- Includes cost for complete installation of steel or aluminum window frames and sash, complete with hardware and mechanical operating devices.
- (8) CAULKING:
- Includes cost for all caulking required for door and window installation.
- (9) PARTITIONS:
- Includes cost required for complete installation of partitions; and all miscellaneous items such as towel racks, mirrors, soap dispensers, urinal screens, hand dryers, etc.
- (10) METAL:
- Includes cost for hauling, handling, and installation of stud for tile-faced partitions.
- (f) This cost code covers labor and material required for all field painting such as structural steel, miscellaneous iron, doors, walls, ceilings, equipment and piping, special codes and identification; hauling and handling of materials; cleaning prior to painting; application of primer and paint; necessary scaffolding and cleanup after painting; and the furnishing of all glass, glazing, and incidental work. Specifically included are:
- (1) STRUCTURAL STEEL AND IRON:
- Includes cost for all painting, and related work, or structural steel for building superstructure and miscellaneous structural steel and iron such as walkways, stairs, windows, doors, handrails, thresholds, and similar items.
- (2) EQUIPMENT, PIPING, AND SUPPORTS:
- Includes cost for all painting, and related work, of equipment that is not furnished with a factory finish; pipe hangers and supports; piping, and code coloring of piping.
- (3) CODE AND IDENTIFICATION:
- Includes cost for all painting, and related work of lettering and code identification, and permanent sign painting.
- (4) OTHER PAINTING:
- Includes cost for all other painting, and related work, such as masonry walls, millwork, plaster walls, plaster and metal ceilings, and concrete equipment foundations.
- (7) 5017 SPECIAL CONSTRUCTION.
- (a) This code covers labor and material costs which are not addressed by other subaccounts under the 501 account such as the labor and material required for installation of bridge and gantry cranes; monorails; conveyors; and pipe handling trolley assemblies, including related electrical feed rails, crane rails, internal wiring, erection, and rigging. Also included are the labor and material required for installation of miscellaneous building equipment attached to and part of the building such as elevators, dumbwaiters, lunchroom equipment, and metal lockers, etc.
- (b) This cost code excludes process equipment and equipment includable in building systems such as monorails, bridge cranes, gantry cranes, pipe handling trolley assemblies, shop equipment, and installation of temporary construction overhead cranes.

(c) Specific elements to be included are:

(1) INSTALLED EQUIPMENT:

Includes cost of labor, material, and installed equipment applicable to the work described above. Cost of equipment includes invoice price and transportation when charged direct. Costs for each size and type of equipment included in this cost code should be readily identifiable in the cost code or supporting records.

(2) CONDUIT:

Includes costs for hauling, handling, fabricating, and installing all conduit for the equipment, with related hangers, supports, junction boxes, and receptacles.

(3) WIRE:

Includes costs for installing wiring for the equipment.

(8) 5018 MECHANICAL.

(a) This account includes the installed cost of building mechanical systems such as refrigeration systems, heating systems, ventilation systems, fire protection systems, plumbing systems and all associated piping, valves, controls, and instruments. Specifically, it covers labor and material required for the installation of any heating, ventilation, and air conditioning systems. Included components are grills, louvers, ductwork, duct insulation, roof ventilators, dampers, unit heaters, related hangers, and supports and self-contained and central distribution units. This cost code also covers labor and material required for the installation of any filter system in connection with an environmental control system. This includes cyclone dust collectors, bag-type filters, electrostatic precipitators, roughing filters, and finishing filters. Labor and material required for the complete installation of piping and equipment for a piping system, including piping, tubing, valves, fittings, hangers, mechanical equipment for a piping system, including piping, tubing, valves, fittings, hangers, mechanical equipment, and insulation, are also included in this account. Piping and equipment used in utility or process systems should be costed with the appropriate system.

(b) Examples of specific elements to be included in this account are as follows:

(1) INSTALLED EQUIPMENT:

Includes cost of labor, material, and installed equipment that is applicable to the work described above. Cost of equipment includes invoice price and transportation when charged direct. Costs for each size and type of equipment included in this cost code should be readily identifiable in the cost code or supporting records.

(2) DUCTWORK:

Includes cost for hauling, handling, fabricating, erecting, and installing duct materials, manually operated dampers, and duct specialties. It also includes ductwork for air conditioning system.

(3) LOUVERS, GRILLS, DIFFUSERS, AND REGISTERS:

Includes costs for the complete installation of louvers, grills, diffusers, and registers.

(4) ROOF VENTILATORS:

Includes costs for hauling, handling, and installing roof ventilators.

(5) DAMPERS - MECHANICALLY OPERATED:

Includes costs for hauling, handling, and installing mechanically operated dampers. This also includes fire dampers.

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(6) TESTING AND BALANCING:

Includes cost for testing, balancing, incidental repairs, and modifications required for the proper operation of the heating and ventilation system.

(7) INSULATION:

Includes cost for labor and material to install insulation on environmental control equipment and distribution system.

(8) CONTROLS:

Includes costs for labor and materials to install all components of the control system, whether pneumatic or electric. This cost code includes all control devices such as thermostats, relays, valves, valve operator dampers, damper operators, local and remote indicators, and recorders. Also includes any other devices used to monitor, record, control, or enunciate conditions and modes of the equipment or the supply, return, or exhaust systems.

(9) ROUGHING FILTERS:

Includes cost for shipping, hauling, handling, and installing roughing or prefilters complete with frames, filter media, retaining clips, bolts, nuts, etc., required to make the installation complete.

(10) FINISHING FILTERS:

Includes cost for shipping, hauling, handling, installing, finishing, or polishing filters complete with frames, filter media, retaining devices, and supports.

(11) PIPING:

Includes cost for hauling, handling, cutting, fabrication, placing, and erecting piping for the system together with related valves, fittings, hangers, expansion joints, and other piping specialties.

(12) INSULATION:

Includes cost for handling, hauling, cutting, and installing insulation for piping.

(13) TESTING:

Includes cost for preliminary testing of the system such as pneumatic or hydraulic pressure testing.

(14) IDENTIFICATION:

Includes labor and material to label, color code, tag, or otherwise properly identify the piping system according to specifications. Painting of pipe and equipment is excluded from this cost code (see Painting and Glazing).

(15) CLEANING:

Includes all cost required to clean, condition, and sterilize the piping system.

(16) UNDERGROUND PROTECTIVE COATINGS:

Includes all costs required to apply protective coatings as specified.

(17) EXCAVATION AND BACKFILL:

Includes all costs of labor and materials to excavate, shore, pump or dewater ditches; form, reinforce, and pour concrete thrust blocks; backfill with any specified material; compaction of backfill; and repairs to damaged concrete or asphalt surfaces as required for the installation of a mechanical system.

(9) 5019 ELECTRICAL.

- (a) This account includes the installed cost of building electrical systems such as electrical lighting systems, electric power systems, emergency light and power systems, building instrumentation systems, building communication systems, and building alarm systems. Each of these systems can be further defined as follows. Building electrical lighting system covers labor and material required for the installation of the electric lighting system for the building or other structure from the low-voltage side of the unit substation or at the service entrance to the building or other structure. It includes lighting transformers, panels, circuits, fixtures, conduit, wire, and the complete installation of the emergency lighting system. An electric power system covers labor and material required for the installation of the electric power system from the building wall through the primary building substation. It also includes switchgear, transformers, potheads, etc. All distribution circuitry and panels required for building items are included in this account. Emergency power and lighting system is defined as all labor and materials required to procure, fabricate, and install the complete functional emergency power and lighting system. Building instrumentation covers labor and material required for installation of instruments and instrument lines in the building from the point of connection to the equipment within the building up to and including the building control room or equivalent. It includes tubing, conduit, wiring, and control panels. This cost code excludes instrument lines from the building control room or equivalent to the central control building (provided in 600 Utilities). A building communication system is defined as all labor and material for the installation of communication systems. This cost code includes conduit, pull wire, outlet boxes, speaker enclosures, mounting panel, and other related equipment. Building alarm systems include the installed cost of fire, smoke, seismic intrusion, and radiological alarm systems to include conduit, instruments, control panels, and detectors.

- (b) Specific elements to be included in the costs of electrical are as follows:

(1) INSTALLED EQUIPMENT:

Includes cost of labor, material, and installed equipment that is applicable to the work described in the second level cost code. Cost of equipment includes invoice price and transportation when charged direct. Costs for each size and type of equipment included in this cost code should be readily identifiable in the cost code or supporting records.

(2) EXCAVATION AND BACKFILL:

Includes cost required for excavation, shoring, backfill, and removal of surplus materials for outside, underground communication duct lines and manholes.

(3) CONCRETE:

Includes cost required for hauling, placing, finishing, and waterproofing concrete in underground communication duct lines and manholes.

(4) REINFORCING AND MISCELLANEOUS STEEL AND IRON:

Includes cost required for hauling, handling, bending, fabricating, placing, tying, and cleaning of reinforcing steel used in underground communication duct lines and manholes.

(5) CONDUIT:

Includes cost for hauling, handling, fabricating, and installing all conduit for the communication systems with related hangers, supports, junction boxes, and receptacles.

(6) POLES AND FIXTURES:

Includes cost for hauling, handling, and complete installation of poles and fixtures. It includes all work required for the erection of poles, complete with hardware, used exclusively for the system.

- (7) MISCELLANEOUS IRON:
Includes cost for installing miscellaneous iron and anchor bolts for electrical power systems which may be required in addition to those covered under Metal.
- (8) SUBSTATIONS:
Includes cost for installing unit substations in the electric power system for process equipment.
- (9) AUXILIARY STRUCTURES:
Includes all costs of labor and material required to assemble, erect, and install a building to house the emergency power and lighting system equipment or motor generator sets.
- (10) INSTRUMENTS AND PANELS:
Includes cost for installing all instruments and panels and the instrumentation connections, together with related preliminary testing.
- (11) SWITCH PANEL:
Includes costs for complete installation of disconnect and switching panels, complete with overload protection devices, interconnecting busses, etc.
- (12) CONTROLS:
Includes all costs of labor and material for the complete installation of all required controls, transfer switches, protective devices, and similar items.
- (13) EMERGENCY LIGHTS:
Includes costs for procuring; fabricating; assembly; testing; handling; and installing, in strategic locations, battery-operated lights. (Use second level cost code 3205 when motor generators, etc., are required.)
- (14) WIRE:
Includes cost for installing wire for electric lighting system. It also includes wiring for the emergency system to the lighting panel.
- (15) FIXTURES:
Includes cost for hauling, handling, and complete installation of all lighting fixtures and related wall switches and receptacles.
- (16) INSTRUMENT VACUUM PUMPS:
Includes cost for installing instrument vacuum pumps and the instrumentation connections.
- (17) INSULATION:
Includes cost for installing instrumentation insulation.
- (18) TUBING:
Includes cost for installing and testing all tubing for instrumentation.
- (19) GROUNDING:
Includes cost for all ground wire, connectors, grids, etc.
- (20) SMOKE DETECTORS:
Includes cost for installation of smoke detection systems, with related wiring, panels, instruments, and similar items.

(21) ALARMS:

Includes cost for installation of fire, intrusion, and radiological alarm systems, with related wiring, panels, instruments, and similar items.

(22) MONITORING:

Includes costs for installation of seismic monitoring systems, with related strain gages, wiring panels, instruments, and similar items.

c. 550 OTHER STRUCTURES.

Includes the installed cost of such structures as dams, retention basins, reservoirs, swimming pools, pits, platforms, underground oil storage reservoirs, and stacks (when not a part of a building), and installed cost of structures and frames used to support such items as heat exchangers, vessels, etc., or special structures such as towers, utilidors, etc., whether inside or outside a building.

(1) 5501 EXCAVATION AND BACKFILL.

This code is identical to account 5011 except that it applies to structures other than buildings.

(2) 5502 CONCRETE.

This code is identical to account 5012 except that it applies to structures other than buildings.

(3) 5503 MASONRY.

This code is identical to account 5013 except that it applies to structures other than buildings.

(4) 5504 METALS.

This code is identical to account 5014 except that it applies to structures other than buildings.

(5) 5505 WOOD & PLASTIC.

This code is identical to account 5015 except that it applies to structures other than buildings.

(6) 5506 THERMAL & MOISTURE PROTECTION.

- (a) Includes the labor and material required for waterproofing, dampproofing, insulating, fireproofing, joint sealing, and traffic topping structures other than buildings. Waterproofing is defined as impervious membranes or coatings applied to walls, slabs, decks, or other surfaces subject to continuous or intermittent hydrostatic head or water immersion. Includes membranes of bituminous, cementitious, elastomeric (liquid-applied or sheet material), sheet metal, bentonite and similar materials, and metal oxide coatings. Includes boards or coatings required for protection of waterproofing. Damp-proofing includes materials installed to provide resistance to moisture penetration through surfaces subject to high humidity, dampness, or direct water contact, but not subject to hydrostatic pressures. Includes bituminous, cementitious, or similar coatings applied to exterior walls below grade, or applied as a protective damp course. Includes silicone, acrylic, or other water repellent coatings applied to exposed surfaces of concrete, masonry, stone, cement, metal, plaster, or similar material. Also includes bituminous, laminated, or plastic vapor barriers. Insulation is defined as thermal insulation for resistance of heat transfer at exterior of structure and at enclosures of high temperature or low temperature spaces. Includes organic or inorganic insulation in form of granules, pellets, rigid boards, fibrous batts, blankets or rolls, and spray or foam applied to walls, roofs, decks, and similar surfaces. Includes insulation applied to perimeter of foundations and under concrete slabs on grade. Vapor barriers integral with insulation are also included. Fireproofing includes special coatings, mineral fiber, and cementitious coverings to provide fire resistance. Joint sealants include elastomeric and nonelastomeric sealants, nonskinning mastic sealants, bituminous

sealants, oil-based caulking compounds, compression gaskets, joint fillers, and related products. Includes primers, backer rods, and bond breaker tape applied to exterior and interior moving and nonmoving joints to prevent penetration of moisture, air, and sound. Traffic topping is defined as surface-applied, waterproof, elastomeric, or composition-type membrane exposed to weather and suitable for normal or light duty traffic (foot or automobile), but not intended for heavy industrial use.

(b) Some specific examples are as follows:

(1) MATERIALS:

Includes costs for materials used for thermal and moisture protection.

(2) STRUCTURAL STEEL AND IRON:

Includes costs for all painting, insulating, and related work for superstructure and miscellaneous structural steel and iron items.

(3) CODE IDENTIFICATION:

Includes costs for all painting and related work of lettering and code identification and permanent sign painting.

(4) INSULATION:

Includes the cost of hauling, handling, fabricating, applying, and cleanup associated with the application of insulation.

(5) SCAFFOLDING:

Includes the cost of hauling, handling, constructing, dismantling, and cleanup of scaffolding required in thermal and moisture protection.

(6) PROTECTIVE COVERING:

Includes the cost of procuring, hauling, handling, fabricating, erecting, and dismantling protective coverings used during the application of thermal and moisture protection materials.

(7) 5507 SPECIAL CONSTRUCTION.

(a) This code covers labor and material costs which are not addressed by other subaccounts under the 550 account such as labor and material required for installation of bridge and gantry cranes, monorails, conveyors, pipe handling trolley assemblies to include related electrical feed rails, crane rails, internal wiring, erection, and rigging. Also included are the labor and material required for installation of miscellaneous equipment which is attached to the structure.

(b) This cost code excludes process equipment, equipment includable in building systems, and standard equipment in the 700 series.

(c) Specific elements to be included are:

(1) INSTALLED EQUIPMENT:

Includes cost of labor, material, and equipment applicable to this account. Equipment cost includes invoice price and transportation when charged direct.

(2) CONDUIT AND WIRE:

Includes costs for hauling, handling, fabricating, and installing all conduit for the equipment, with related hangers, supports, junction boxes, and receptacles.

(8) 5508 MECHANICAL.

This code is identical to account 5018 except that it applies to structures other than buildings.

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(9) 5509 ELECTRICAL.

This code is identical to account 5019 except that it applies to structures other than buildings.

d. 600 UTILITIES.

Includes the installed cost of systems which service the project as a whole and generally extend between individual buildings or process units.

(1) 6100 COMMUNICATION SYSTEMS.

Includes the installed cost of telephone, intercommunication and teletype equipment; telephone instruments and protective devices; lines, poles, cables, and conduits; and stationary and associated portable radio transmitting and receiving equipment.

(2) 6150 ELECTRIC TRANSMISSION AND DISTRIBUTION SYSTEMS.

Includes the installed cost of all transmission and distribution lines, poles, towers, grounding systems, substations, transformers, controls, cables, conduits, services, meters and protective devices; lighting fixtures, wire, poles, standards, and related accessories supplying electric service.

(3) 6210 ALARM SYSTEMS.

Includes the installed cost of equipment necessary for receiving and transmitting alarms, including control wiring (both cable and open); and other associated overhead and underground equipment which provides fire, security, radiological or environmental protection or warning.

(4) 6250 GAS TRANSMISSION AND DISTRIBUTION SYSTEMS.

Includes the installed cost of equipment involved in the storage, transmission, and distribution of natural and artificial gas, including pipelines, services, and associated regulating and metering equipment of buildings served.

(5) 6300 IRRIGATION SYSTEMS.

Includes the installed costs of canals, ditches, waterways, flumes, pipelines, and equipment used for irrigation purposes.

(6) 6400 SEWERAGE SYSTEMS.

Includes the installed cost of sewerage treatment and disposal facilities, including manholes, mains and lateral lines to point of tie-in with buildings served; and any septic tanks.

(7) 6450 STEAM GENERATION AND DISTRIBUTION SYSTEMS.

Includes the installed cost of all equipment used for the generation and distribution of steam to the point of tie-in to buildings where such steam is utilized primarily for heating and for furnishing power to equipment.

(8) 6500 WATER SUPPLY, PUMPING, TREATMENT, AND DISTRIBUTION SYSTEMS.

Includes the installed cost of wells, pumping, water treatments, and distribution facilities to the point of tie-in with buildings served.

(9) 6600 OIL PIPING AND DISTRIBUTION SYSTEM.

Includes the installed cost of pipelines, pipe racks, raceways, valves, pumps, metering devices, and bulk storage tanks between the oil transporting vehicle (truck, barge, tanker, or pipeline) and bulk storage tanks of other piping systems.

(10) 6900 OTHER UTILITIES.

Includes the installed cost of utility systems not specifically included under the 600 account such as a compressed air system, or an anhydrous hydrogen fluoride gas system.

e. 700 SPECIAL EQUIPMENT/PROCESS SYSTEMS.

Includes the installed cost of towers, reactors, drums, trays, storage tanks (not associated with site utilities), cyclones, etc., less the cost of supports or supporting structures (see 5600).

(1) 7010 VESSELS.

Includes the installed cost of towers, reactors, drums, trays, storage tanks (not associated with site utilities), cyclones, etc., less the cost of supports or supporting structures (see 5600).

(2) 7020 HEAT TRANSFER.

Includes the installed cost of heat exchangers, heaters, stacks, steam boilers, furnace cooling towers, ejectors, brazed core exchangers, desuperheater and cooler, and refrigeration equipment.

(3) 7030 MECHANICAL EQUIPMENT.

Includes the installed cost of pumps, drivers, compressors, blowers, actuators, electrical generators, filters, valves, separators, solids handling equipment, scrubbers, mixers, meters, agitators, silencers, and other items of mechanical equipment.

(4) 7040 PACKAGE UNITS.

Includes the installed cost of off-the-shelf units which are used in a process (e.g., gas waste treatment package, clarifier package, desulfurization package, demineralization, deaerator, incinerator, flare, and odorization package).

(5) 7050 PIPING.

Includes the installed cost of process piping to include pipe, pipe racks, raceways, etc.

(6) 7060 ELECTRICAL.

Includes the installed cost of all process electrical transmission and distribution equipment not considered a utility system. Costs include wire, cable, poles, insulators, towers, grounding systems, substations, transformers, controls, meters, lighting, conduit, piping, distribution fumes, and control panels.

(7) 7065 INSTRUMENTATION.

Includes the installed cost of all process instrumentation whether electrical or nonelectrical such as pneumatic and pressure instruments. Cost includes all associated wire, cable, tubes, pipes, grounding equipment, poles, raceways, meters, and control panels.

(8) 7070 PROTECTIVE COVER.

Includes the installed cost of process insulation, painting, fireproofing, refractory lining, waterproofing, and dampproofing.

(9) 7080 REACTOR COMPONENTS.

Includes the installed cost of reactor support, reactor structure, reactor internals, reactor control devices, instrumentation and control devices, monitoring system, leak detection equipment, cooling equipment, makeup water system, inert gas system, fuel handling tools and equipment, service platforms, etc.

f. 800 IMPROVEMENTS FOR OTHERS.

Includes the cost of improvements made by DOE to land, buildings, structures, building services, and utility systems not owned by DOE. Plants, laboratories, and similar facilities constructed by DOE on land owned by others are not to be classified in this category.

g. 810 DEMOLITION.

Includes the cost of wrecking; dismantling; cutting; drilling; and removing existing structures, equipment, and materials; as well as any excavation required to facilitate demolition and the

cleaning, stacking, loading, hauling, and unloading of material for salvage and/or disposal when such activity represents a major activity in accomplishment of the project. Minor, routine demolition will be listed under improvements to land.

h. 820 TUNNELING.

Includes the complete costs of constructing a tunnel to include excavation, drilling, blasting, mucking, shoring, timbering, bolting, mechanical utilities (air, water, and vent lines), surface construction, installation (shaft collars, portal facings, retaining walls, rock, bolts, fences, gates, hatches, doors, muck dumping facilities, anchors, guys, deadmen, buildings, foundations, docks, etc.), and associated mobilization and demobilization.

i. 830 DRILLING.

Includes the complete cost of drilling to include purchase or lease of the drilling rig associated material mandrels, jet subs, drill collars, drill pipe, kellys, goosenecks, casing, detergent, mud additives and other chemicals, tool repair, installing casing (double jointing, lugging, cutting lifting eyes, casing, and installing guidelines), installing the drilling rig, correcting problems (plugback to correct well bore deviations), cleaning out and conditioning the hole, coring, sidewall, sampling, dewatering, fishing, laboratory support, building support structures, and safety fences.

4. STANDARD EQUIPMENT.

a. 710 HEAVY, MOBILE EQUIPMENT.

Includes the cost of heavy, mobile equipment (other than motor vehicles) such as concrete mixers, power shovels, cranes, compressors, rollers, road graders, tractors, farm implements, boats, and barges. The cost of trucks is included in code 725.

b. 715 HOSPITAL AND MEDICAL EQUIPMENT.

Includes the cost of hospital, clinical, and dental equipment such as hospital beds, dentist chairs, instruments, sterilizers, and other scientific equipment used by dentists and doctors.

c. 720 LABORATORY EQUIPMENT.

Includes the installed cost of laboratory equipment such as microscopes, analytical balances, electroanalyzers, oscillographs, refractometers, light sources, vibrometers, and other scientific equipment usually associated with laboratories. The costs of furniture, fixtures, and shop equipment are included in codes 730 and 755.

d. 725 MOTOR VEHICLES AND AIRCRAFT.

Includes the cost of passenger cars, trucks, buses, jeeps, trailers, airplanes, and fire trucks.

e. 730 OFFICE FURNITURE AND EQUIPMENT.

Includes the installed cost of office furniture and equipment such as machines, desks, drafting sets, safes, photographic equipment, copy-making equipment, printing equipment, and other office equipment regardless of where located. The cost of automatic data processing equipment is included in code 770.

f. 735 PROCESS EQUIPMENT.

Includes the installed cost of equipment used specifically in product manufacturing and processing, including associated measurement and control instruments.

g. 740 RAILROAD ROLLING STOCK.

Includes the installed cost of railroad rolling stock such as locomotives and cars.

h. 745 REACTORS AND ACCELERATORS.

Includes the installed cost of reactors; proton synchrotrons; electron synchrotrons; cyclotrons; linear accelerators; Van De Graff generators; and accessory equipment, including associated measurement and control instruments.

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i. 750 PORTABLE SECURITY AND PROTECTION EQUIPMENT.

Includes the installed cost of man and vehicular portable equipment used for police, security, and fire protection purposes. Cost of vehicles is in code 725, and cost of installed alarm systems is in code 621.

j. 755 SHOP EQUIPMENT.

Includes the installed cost of shop equipment such as lathes; drilling machines; rolling mills; hoists; grinders; forges; pipe-cutting machines; presses; saws; shapers; and other equipment usually associated with shops, garages, and service stations. Similar equipment used in laboratories and other areas for research purposes should also be identified by this code.

k. 760 RESERVE CONSTRUCTION EQUIPMENT POOL.

Includes the installed costs of construction and automotive equipment held for the purpose of maintaining a reserve pool for use in emergencies as part of the DOE Mobilization Program, or for secondary use in future construction programs.

l. 770 AUTOMATIC DATA PROCESSING (ADP) EQUIPMENT.

Includes the installed cost of all equipment used in ADP such as (1) punched card and/or tape equipment, whether used alone or in conjunction with electronic computers; (2) electronic computers and all peripheral or auxiliary equipment; (3) data transmission systems employing devices communicating or transmitting data from place to place for processing in an ADP system; (4) all other equipment that is used in ADP in conjunction with punched card equipment or electronic computers; and (5) the initial package of software that is required to make the system operational. Equipment such as flexowriters, IBM typewriters, equipment reading the results of experiments, etc., shall be classified as ADP equipment when used primarily in conjunction with an ADP system. Excludes the cost of equipment such as analog computers, card and/or tape file cabinets, and air conditioning for the processing room. Also, excludes the cost of automatic data recording or electronic control systems used to furnish operating guidance for control of machine tools, equipment used in process operations, reactors, accelerators, etc.

m. 799 MISCELLANEOUS EQUIPMENT.

Includes the installed cost of furniture and fixtures for hotels, dormitories, and apartments; laundry equipment; restaurant, cafeteria, and canteen equipment; and other miscellaneous equipment not includable in other codes.

5. INDIRECT CONSTRUCTION COSTS.

Subsidiary indirect construction cost accounts are described below.

a. ENGINEERING, DESIGN, AND INSPECTION.

(1) SURVEYS, GEOLOGICAL STUDIES, AND TESTS.

Includes cost of topographical and other field surveys, soil tests, load tests, geological studies, test borings, or other subsurface investigations.

(2) PRELIMINARY WORK.

Includes cost of preliminary studies, sketches, cost estimates, layout plans, and reports.

(3) DESIGN.

Includes the cost of design services consisting of the preparation of working drawings, specifications, cost estimates based on working drawings, evaluation of bids, and the checking of shop drawings.

(4) CONSULTING SERVICES.

Includes cost of expert technical or professional assistance to the extent authorized by the contract.

(5) DESIGN OF SPECIALIZED EQUIPMENT.

Includes the cost of design of specialized equipment by the A-E contractor or subcontractor as approved by the contracting officer.

(6) EXPEDITING OR PROCUREMENT.

Includes the cost of expediting or procurement of materials and equipment for the construction project.

(7) INSPECTION.

Includes the cost of inspection of construction work to secure compliance with plans and specifications, field or laboratory tests of workmanship and materials, providing lines and levels to which construction may be referred, preparation of progress reports or estimates of construction performed for payments or other purposes, and the preparation of record drawings.

(8) MISCELLANEOUS.

Includes the cost of items allowable under the contract or amendments thereto that are not susceptible of classification to any one of the above accounts. Such items include bonds and insurance; materials and supplies for the A-E contractors' use; patents; purchase designs and royalty payments; structures and facilities of a temporary nature used by the A-E contractor; taxes, fees, and charges levied by public agencies of personnel; the transportation of personal household goods and effects; losses not compensated for by insurance; litigation; A-E contractor's fees; and other costs specifically certified in writing by the contracting officer according to the terms of the contract.

b. GENERAL AND ADMINISTRATIVE.

(1) ADMINISTRATION.

Includes salaries, travel, and other expenses for the overall administration of the project.

(2) SUPERINTENDENCE.

Includes salaries; travel; and other expenses of those supervising construction, including construction superintendents, assistants, and their secretaries and stenographers. Only general superintendents are included here. Superintendents assigned to specific portions of the project are charged directly to the cost accounts of the specific portions.

(3) CONSTRUCTION CONTRACTOR'S ENGINEERING.

Includes salaries; travel; and other expenses of engineering personnel, including engineers, assistants, and their secretaries and stenographers responsible for plan files, plan detailing, plan distribution, line and grades estimating, material take-offs, and design of contemporary construction facilities. When regular A-E work is performed by a construction contractor, such costs are chargeable to the applicable subdivisions of Engineering, Design, and Inspection.

(4) ACCOUNTING.

Includes salaries; travel; and other expenses for accounting staff, including accountants, timekeepers, clerks, and their secretaries and stenographers.

(5) PROCUREMENT.

Includes salaries; travel; and other expenses of personnel responsible for purchasing and expediting materials, supplies, and equipment.

(6) PERSONNEL.

Includes salaries; travel; and other expenses of personnel for recruitment, employment, and employee relations activities.

(7) LEGAL.

Includes salaries, travel, other expenses, and legal fees.

(8) SECURITY.

Includes salaries, travel, and other expenses of personnel for security protection.

(9) OFFICE SUPPLIES AND EXPENSES.

Includes the cost of miscellaneous expenses of administrative offices, including stationery; forms; blueprints; maps; plans; documents reproduced by blueprinting and other processes; work photographs; telephone and telegraph, including operators; janitor expense; heating; lighting; water; depreciation of office buildings and equipment; repairs and maintenance of office buildings and equipment; messengers; clerks; and other office employees not chargeable to other accounts.

c. OTHER INDIRECT.

(1) PAYROLL INSURANCE.

Includes the cost of workmen's compensation insurance not charged elsewhere.

(2) INSURANCE.

Includes the cost of insurance, other than payroll, carried by the contractor in connection with the construction work and not charged elsewhere.

(3) DAMAGES NOT COVERED BY INSURANCE.

Includes the cost of damage settlements not covered by insurance and not chargeable elsewhere.

(4) PAYROLL TAXES.

Includes the cost of contractors' contributions for social security not charged elsewhere.

(5) TAXES OTHER THAN PAYROLL.

Includes the cost of business and property taxes incurred during the construction period.

(6) HOLIDAY AND VACATION PAY.

Includes the cost of holiday and vacation pay not charged elsewhere.

(7) SIGNUP AND TERMINATION PAY.

Includes the cost of signup and termination pay not charged elsewhere.

(8) RETROACTIVE PAY.

Includes the cost of retroactive pay adjustments. This account is to be used only when actual distribution of retroactive pay adjustments would be burdensome or the specific projects affected are closed.

(9) REPORTING TIME.

Includes the cost of time given employees who report for work when no work is available because of weather or other conditions.

(10) WELDING TESTS.

Includes the cost of conducting welding tests at the job site or elsewhere.

(11) CONTRIBUTION TO WELFARE PLANS.

Includes the cost of contributions to labor union welfare plans not charged elsewhere.

(12) TRANSPORTATION OF WORKMEN.

Includes the cost of transporting employees engaged in the construction work to and from site locations not charged elsewhere.

(13) MOTOR POOL OPERATIONS.

Includes the cost of operating a pool of motor vehicles for general, administrative services. Costs of operating automobiles specifically assigned to other services are not to be included.

(14) AIRCRAFT OPERATION.

Includes the cost of aircraft operation chargeable to construction projects, generally distributed to this account from equipment clearing accounts.

(15) MEDICAL AND FIRST AID.

Includes the cost of medical, first aid, and hospital services.

(16) SAFETY.

Includes the cost of all safety programs carried on during the course of the construction contract. (Costs of glasses for welding operations; gloves for linemen; scaffold railing for bricklayers; etc., are trade safety measures and, as such, are charged to the appropriate cost accounts rather than to this account.)

(17) FIRE PROTECTION.

Includes the cost of providing fire protection.

(18) MAINTENANCE OF GENERAL CONSTRUCTION PLANT.

Includes the cost of maintaining and operating general construction plant facilities not chargeable to other accounts. It includes depreciation on general Site Improvement, Temporary Land Improvements, General Plant, and Miscellaneous Equipment.

(19) SMALL TOOLS.

Includes the cost of small handtools and of operating the toolroom. Included are costs of tool boxes, tool shanties, wages of toolroom boys, costs of rehandling and sharpening tools. Costs of boots, raincoats, and other protective clothing issued to workmen are included. Does not include handtools used in shops. The costs of pneumatic and electric tools larger than handtools are chargeable to Miscellaneous Equipment.

(20) DRINKING WATER AND SANITATION.

Includes the cost of supplying drinking water and of toilet facilities.

(21) LIGHT AND POWER.

Includes the cost of light and power that is not chargeable to other accounts.

(22) HEAT.

Includes the cost of heat that is not chargeable to other accounts.

(23) COMPRESSED AIR.

Includes the cost of operating the compressed air system that is not chargeable to other accounts.

(24) WATER.

Includes the cost of water that is not chargeable to other accounts.

(25) GENERAL CLEANUP.

Includes the cost of general cleanup or yard janitor service that is not chargeable to other accounts.

(26) CAMP OPERATION.

Includes the cost of and revenues from the operation of construction camp facilities.

(27) CAMP OPERATION COSTS.

Includes the cost of operation and maintenance including depreciation on construction camp plant. This account should be subdivided to the extent necessary to account for and control these costs.

(28) CAMP REVENUES.

Includes the cost of revenues derived from operating construction camp facilities. This account should be subdivided to the extent necessary to account for and control these revenues.

(29) RECOVERY OF INDIRECT COSTS.

Includes all credits for indirect costs included in billings to others.

(30) CONTRACT FEE.

Includes all charges for the fee earned by the contractor in accordance with the terms of the contract.

6. CONTINGENCY.

- a. Includes additional funds which may be required to meet unexpected design or construction problems. The amount of funds required is a function of the degree of technological advance represented by the design, complexity of the project, the likelihood that changing regulatory requirements could require modification of the design, and the stage of design.
- b. Contingency can be computed either individually by component element of the estimate then summed, or by applying a percentage "add-on" to the estimated cost; but both methods cannot be used simultaneously in a cost estimate.

7. ESCALATION.

- a. Escalation includes the combined effects of inflation and real escalation. Inflation can be defined as an increase in the amount of money required to pay for labor and material which results from resource depletion, increased demand with limited supply, etc. Real escalation is independent of, and in addition to, inflation.
- b. Uncertainty with respect to renegotiated labor agreements and other localized future economic conditions should be accommodated as real escalation.
- c. The total escalation should be computed by using those methods outlined in a separate cost guide on economic escalation published by the ICE Staff.

CHAPTER 7

DOUBLECHECKING THE ESTIMATE

After the estimate has been prepared, a check for completeness and correctness should be made. This check includes but is not limited to the following.

1. Check mathematical extensions and additions for correctness.
2. Check takeoff for omissions or oversights. For example, a project that is primarily mechanical in nature may have some electrical, structural, civil work, or demolition required with it.
3. Compare the construction labor hours with the construction schedule to determine a labor force density. Evaluate whether the labor force density can adequately function on the construction site, whether shift work might be required, or whether the total labor hours are adequate to complete the required work. These are judgment considerations but they are very helpful in finding inadequacies in the estimate.
4. Check the calculations of the construction indirect costs. Verify that the vendor quotations used as direct costs do not include indirect costs.
5. Compare the construction cost with any similar project for an order of magnitude check.
6. Compare the Title I estimate with the conceptual estimate and explain any discrepancies.
7. Compare the Title II estimate with the Title I estimate and explain any discrepancies.

CHAPTER 8

CONTINGENCY

Contingency is added to an estimate to cover costs which cannot be defined at a given stage of estimate development. This does not mean, for example, that any project which is 50 percent designed will have the same percent contingency. Each project must be analyzed on an individual basis.

The areas to consider in determining the contingency are:

1. The Type of Project. For example, a prefabricated metal building does not have nearly as many questionable areas as does a nuclear reactor modification; hence, the contingency percentage should be higher on the nuclear reactor modification.
2. The Completeness of Design. Some projects after Title II have more detail than other projects with similar scope. The incomplete design will justify a higher contingency.
3. Firm Quotations. If firm quotations are included as part of an estimate, contingency need not be included on that portion.

After considering the above factors, the estimator should look into each area of the estimate and apply a contingency to each part of the estimate. This instance may also justify additional contingency be added on due to the possibility of encountering existing underground lines.

The following guidelines are general averages in use in the Department for general construction projects:

Completeness of Design.

1.	Planning	25% to 35%
2.	Conceptual	20% to 25%
3.	Title I	10% to 20%
4.	Title II	10% to 15%
5.	Above low bid	5% to 10%

Types of Construction.

The percentage used for contingency as determined from the above guidelines should be altered to reflect the type of construction. The following percentages are accumulatively added or deducted from the above percentages:

1.	Underground lines near Central Facility	+2% to +5%
2.	Buildings	-1% to -3%
3.	Quality Level I and II Work	+10% to +15%
4.	Quality Level III Work	No Change
5.	Contaminated areas	+5% to +10%

After a rate of contingency is determined, the contingency is applied to all portions of the estimate including escalation.

In assessing contingency for process plants in emerging technologies, both the state of the technology and the stage of the design are considered on a sub-process basis and then summed. Then the two categories are added (design and technology development) to obtain total project contingency. The following values were derived by private industry and have been useful to the ICE Staff.

PROCESS PLANTS TECHNOLOGY DEVELOPMENT CONTINGENCIES

<u>Type Category</u>	<u>Contingency</u>	<u>Type Category</u>	<u>Contingency</u>
Experimental ¹	25 percent and up	Demonstration ³	5 percent - 10 percent
Pilot ²	10 percent - 25 percent	Commercial ⁴	0 percent - 5 percent

Notes: $\frac{1}{2}$ / Concept supported by laboratory studies and initial hardware development.
 $\frac{3}{3}$ / Concept supported by small pilot facility.
 $\frac{4}{4}$ / Concept verified by integrated demonstration plant.
— Significant commercial experience.

DESIGN/COST ESTIMATE CONTINGENCIES

<u>Design Stage</u>	<u>Estimate Type</u>	<u>Contingency</u>
Conceptual	Preliminary	20 percent - 25 percent
Preliminary	Budget	15 percent - 20 percent
Detailed	Definitive	5 percent - 15 percent

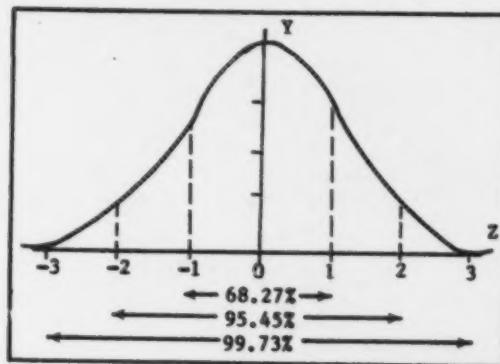
When statistical methods are used to derive cost, confidence intervals are developed to address uncertainty. In contrast to providing an expected value or point estimate, confidence intervals pertain to interval estimates. Providing certain basic statistical assumptions are met, such as randomness of sample, an estimator can state what percent of the time a given estimate's true value will fall within a range of values described statistically.

Data samples serve to represent the actual statistical universe. As the universe departs from a normal distribution, the distribution of sample means is also pulled away from the normal curve form, but much more slowly. Thus, when sufficient sample data points are available, the distribution of sample means will remain normal to a satisfactory degree of approximation.

The estimator will usually develop the mean and standard deviation for the data sample. Through common statistical techniques, an interval of values about the mean, based on the desired degree of confidence, can be developed. Because sample means are distributed as a normal curve, degrees of confidence can readily be related to integer standard deviation values where:

<u>Standard Deviation</u>	<u>Percent</u>
- One	= 68
- Two	= 95
- Three	= 99

Or in graphic form:



Thus, with the selected degree of confidence, it is possible to establish the interval range to be considered. The estimator can then provide the decisionmaker with a confidence statement describing the interval; for example, statistical analysis indicates that the true value of this estimate should fall within the specified interval 95 percent of the time.

When regression analysis is used to derive CERs, prediction intervals are developed to determine the level of confidence of the estimate. See the paragraph on Prediction Intervals in Chapter 13 for a full discussion of this subject.

CHAPTER 9

ECONOMIC ESCALATION

Procedures for treating economic escalation are covered in Volume V (dated May, 1982) of the cost estimating manual series. Questions in this area should be addressed to Bill Adair of the Independent Cost Estimating Staff, telephone number (202) 252-9697.

CHAPTER 10

PROJECT REVIEW AND CONTROL

(This section on project review and control was developed by the DOE Oak Ridge Operations Office (DOE-ORO) and is included in this manual as an illustrative way that review and control can be handled. Each organization is encouraged to develop its own procedures for handling these tasks if local conditions indicate different methods should be used.)

Current working estimates are required for cost control on projects and to determine whether the project is within authorized funds during the course of design and construction. Working estimates will be kept under constant review by all participants to assure that they currently reflect the latest cost and design data available, realistic estimated costs to complete remaining work, allowance for contingency based on detailed analysis, and uncertainties in the project. Formal detailed working estimate reviews on projects are conducted quarterly by all project participants beginning after the initiation of Title I and continuing throughout the life of the project to determine whether the project is being maintained within authorized funds and approved schedules. The Congressional Data Sheet serves as the basic document for DOE-ORO project control and establishes the overall project scope, total official project estimate, and the schedule under which the project is to be conducted.

DOE-ORO has developed detailed procedures for cost control and preparation and review of current working estimates (detailed project reviews); basic data requirements and procedures for detailed project reviews are described in the following paragraphs.

Upon completion of conceptual design for a project, the following basic documents will be prepared by the operating contractor for use in project control and submitted to DOE-ORO for review and approval.

1. MILESTONE CHART.

This is the basic tool of project control that summarizes results of current detailed working estimate reviews. The project is broken down into manageable segments for control purposes consistent with the construction cost code manual, WBS chart, and cost collect system. Each segment is entered on this chart as a numbered milestone item. Each milestone item in a project will reflect the complete data under the headings shown in the chart.

2. CONTINGENCY ANALYSIS.

Contingency analysis will be performed on a milestone item-by-item basis.

3. PROCUREMENT, SCHEDULE AND STATUS REPORT.

All procurement (including in-house shop fabrication by operating contractors) to be accomplished by operating contractors or prime CPFF construction contractors will be identified on an item-by-item basis and listed in a procurement schedule and status report by milestone item. Complete data for each item of procurement will be shown therein.

4. SCOPE CHANGES.

Formal procedures will be developed for the submittal and consideration for approval of necessary scope changes by an A-E or operating contractors to DOE-ORO. Upon approval by DOE-ORO the changes will be included in the revised baselines and become the basis for future project reviews.

All participants in the project will be involved in the detailed quarterly reviews with the responsibilities of each described as follows.

- a. DOE-ORO Engineering Division. This division provides current working estimates for prime architect-engineer and DOE direct participation to the operating contractor and reviews and approves all draft material making up the detailed review prior to issuance in final form.
- b. Operating Contractor. The operating contractor is responsible for detailed review and consolidation of draft material for submittal to DOE-ORO Engineering Division for review and approval. Draft material to be prepared by the operating contractor consists of backup estimates for operating contractor engineering costs broken down by milestone items, a backup estimate for each milestone item which includes all participants (without engineering costs), procurement schedule and status report, milestone chart, and contingency analysis. The operating contractor PM or PJ must provide documentation of this acknowledgement of the authenticity and completeness of the data used in the report. After approval by DOE-ORO Engineering Division, the operating contractor will place the milestone chart and contingency analysis into final form and issue to project participants.

- c. DOE-ORO Construction Division. The Construction Division provides current working estimates for prime A-E Title III engineering, prime CPAF construction, and prime fixed-price construction in progress at Oak Ridge to the operating contractor for use in developing the overall project estimate. Where the work has not yet been estimated by the CPAF construction contractor or the prime fixed-price contract has not been awarded, estimates prepared by the operating contractor and/or the prime A-E will be used.

As indicated in other sections of this manual, all estimates and actual cost data will be on the basis of the construction cost code of accounts applicable to each project and to the other provisions of this estimating manual. These provisions are applicable to all detailed working estimate reviews throughout the life of the project.

The DOE-ORO Engineering Division will periodically issue schedules for completion of quarterly project reviews for each project. For certain major projects, special instructions that may be required from time to time will be provided by separate correspondence from the ORO Engineering Division.

In conducting detailed quarterly project reviews, design status, procurement status, and actual cost data cut-off dates will be estimated for each project review in order to provide a common basis for developing the current cost estimate. Each participant involved in the project will provide current estimates for its portion of the project work. All estimates will be based upon actual cost data as of the established cost cut-off date and the estimated cost to complete each segment of work giving full consideration to the status of design, procurement, and construction.

Each detailed working estimate will be conducted by all participants in accordance with the following procedures:

- (1) Engineering Design and Inspection. For prime architect-engineer participation, the current working estimate for prime A-E Titles I and II engineering costs and Title III engineering costs will be reviewed by the ORO Engineering Division, except for prime A-E Title III at Oak Ridge, which is the responsibility of the ORO Construction Division. The current working estimate and cost incurrence through the cut-off date for prime A-E participation will be furnished by the ORO Engineering to the operating contractor broken down by milestone items and Titles I, II, and III for use in preparing the overall draft review. Estimates of engineering costs for operating contractor participation will be developed in accordance with Section 3.0 titled, "Estimated Engineering Costs," and required backup provided.
- (2) Procurement and Shop Fabrication By Operating Contractor. Estimates for operating contractor procurement and shop fabrication will be based on current data from the procurement status report as of the established cut-off date, which will reflect actual purchase order amounts, where awarded, and fabrication shop estimates where available.
- (3) Prime CPAF Construction. Where sufficient design is available for a portion of, or a total milestone item, the CPAF construction contractor will provide the current working estimate indicating the basis therefor and including field change orders in the estimate as of the cost cut-off date. These estimates will be reviewed by the DOE-ORO Construction Division and changes or concurrence therein will be indicated and a copy forwarded to the DOE-ORO Engineering Division and to the operating contractor. In those cases where the CPAF construction contractor has not yet prepared an estimate for a milestone item, the estimate for CPAF construction will be prepared by the prime A-E and/or operating contractor for use in the current working estimate. Where only a portion of a milestone item has been estimated by the CPAF construction contractor, the estimate for the balance of the work will be prepared by the prime A-E and/or operating contractor and combined with the partial CPAF contractor estimate to provide the total estimate applicable to the milestone item. Review of and concurrence in estimates prepared by CPAF contractors by the ORO Construction Division is applicable for work at Oak Ridge only. When prime CPAF construction is involved at other sites, the responsibility for review of estimates prepared by such contractor will be assigned by DOE-ORO.
- (4) Fixed-Price Construction. Until a fixed-price construction contract is awarded, the latest estimate prepared by the prime A-E and/or operating contractor will be included in the current working estimate review. After award of a fixed price construction contract, the current contract amount plus estimated costs of changes will be included in each working estimate review. At Oak Ridge, the current working estimates for awarded prime fixed-price construction contracts will be provided to the operating contractor by the ORO Construction Division for incorporation into the overall review.

- (5) Operating Contractor Field Work. The current scope and cost estimate for operating contractor field participation will be reflected in each estimate review.

Based on the above feeder information, the operating contractor will prepare a backup estimate for each milestone item, excluding engineering and contingency. As each backup estimate is completed, a copy will be sent to the ORO Engineering Division for review and comment. Backup estimates for operating contractor engineering will be prepared in accordance with Section 3.0 and submitted to the ORO Engineering Division for review. Each backup estimate will contain an explanation of significant changes from the previous estimate.

From the various backup estimates, a draft milestone chart will be prepared by the operating contractor, which will be complete in every respect including current design, installation, and construction schedule data. A detailed contingency analysis will be made on an item-by-item basis and reflected on the established format. These draft data will also be submitted to the ORO Engineering Division for review.

The ORO Engineering Division will review all backup estimates, milestone charts, and the contingency analysis. As necessary, this review will be coordinated within the ORO Office of Assistant Manager for Construction and Engineering and other ORO Divisions. Any comments arising from review of the draft material will be resolved with the operating contractor who will make any required changes in the data.

After receipt of DOE-ORO approval of the draft data, the operating contractor will place the milestone chart and the contingency analysis in final form, and issue copies thereof to all participants for use as working documents in schedule and cost control, and will transfer this data to a Project Cost, Estimate and Schedule Summary for the formal quarterly status report to DOE-ORO. Other forms and/or formats may be required at various times or on specific projects. These will be clearly defined when required.

CHAPTER 11

USE OF PARAMETRIC ESTIMATING AND LEARNING CURVE TECHNIQUES AND SUPPORTIVE DATA BASES

Parametric cost estimating has been used successfully by the military for years to obtain cost information on major systems acquisitions. The Department of Defense (DOD) found this technique extremely effective when estimating advanced state-of-the-art projects especially before detailed design was completed.

Parametric estimating utilizes statistical techniques, including regression analysis, to find correlations between costs and project performance or project design parameters. For example, speed and weight proved to be excellent predictors of airframe costs.

Even though parametric techniques are generally used at higher level aggregations in the work breakdown structure, they can be applied to any level of detail that "take-off" or "bottoms-up" techniques are applied. For example, the ICE Staff has recently collected data and built Cost Estimating Relationships (CERs) that will estimate cost at the total plant level, and others that will estimate the cost of pumps and cooling towers, etc.

In order to develop CERs, good cost data on analogous systems must be collected and normalized. As seen in succeeding chapters, this is a difficult task. Not only must cost be collected, but project performance and design characteristics must be recorded so they can be statistically tested to see if they "control" or "drive" cost. If so, these parameters become the independent variable in the CERs which are used for future estimating.

Learning curve is a phenomena discovered by the aerospace industry that deals with production line costs. Learning takes place in an assembly line project resulting in lower unit costs as more units are produced. Basically, learning-curve theory states that each time the total quantity of items produced doubles, the cost per item is reduced to a constant percentage of its previous cost. Learning-curve theory would have an ideal applicability to production runs of such things as heliostats for solar systems and centrifuges for gas diffusion plants.

The section on cost models was included to illustrate what models are and how they are constructed. Cost models can vary from a simple one formula model to an extremely complex model that involves hundreds or even thousands of calculations. Cost models will become increasingly more available to the DOE cost estimators in the future.

The ICE Staff has been actively collecting and normalizing cost data over the past 2 years. It has normalized the data and constructed CERs for both synthetic fuels and nuclear process plants. This information is now being printed and will be disseminated soon.

Data bases exist everywhere and take many forms. Various kinds of cost can be found in warehouses and file cabinets in Operations and Headquarters Offices. Some Operations Offices use the data to construct rule-of-thumb ratios and other tools to aid their estimators. Such an example is provided by INEL in the chapter on Cost Data Bases. DOE cost estimators should take every opportunity to share cost data and CERs with one another.

The following chapters provide excellent examples of how to collect and normalize data and how to construct and use CERs, and to use learning curves. The statistical illustrations are written at the basic level and only a knowledge of algebra is required to understand the material. Most of the material was developed by DOD under contract in 1971. The ICE Staff attempted to find a similar treatment that used construction project examples, but was unsuccessful. Even though military hardware examples are used, the test is outstanding and the theory is equally applicable to DOE projects.

A basic understanding of the material presented in this volume will allow an estimator to use the CERs developed by the ICE Staff, and also to develop and use his own.

BEST DOCUMENT AVAILABLE

CHAPTER 12

DATA COLLECTION AND ADJUSTMENT

The Government has been collecting cost and program data on weapon and support systems for many years--sometimes in detail, sometimes in highly aggregated form. Consequently, it is surprising that the right data seldom seem to be available when an estimating job is required. It appears that the needs of the cost analyst have not always been considered in designing the many information systems that have been used by the Army, Navy, and Air Force. Data have been collected for program control, for program management, and for program audit, but this information has never been systematically processed and stored. Instead, after a few years it has generally been discarded or placed in not readily accessible warehouses. Moreover, the data were often inconsistent since they were gathered according to the requirements of each military service and each program manager. To obtain the data to develop estimating relationships, the analyst has had to use contractor records.

1. DATA COLLECTION.

The Cost Information Report (CIR) was established in 1966 to alleviate the problem of data collection. This reporting system was designed to collect costs and related data on major contracts for aircraft and missile space programs to assist industry and Government in estimating and analyzing the costs of these programs. Information from other sources (contract records, management records, and the like) can be processed to complement the CIR and thus make complete program histories available. (Subsequent chapters of this study describe the methods of analysis that this information was designed to serve.) As data accumulate over a period of years, the need for ad hoc collection efforts should diminish. These efforts will never disappear completely, however, as information systems cannot be designed to satisfy every data requirement. Under ideal conditions, the analyst would have data with which to develop estimating techniques responsive to any demand, but even the largest contractors are reluctant to allocate the resources required to put estimators in such a favorable position, and the cost to the Department of Defense (DOD) for such data--much of which would seldom be used--would be prohibitive. However, a Government analyst or estimator has one great advantage over his counterpart in industry: He has a much broader data base to draw on.

A minimum data requirement exists for any given job, but before data collection begins the analyst must consider the scope of his problem, define generally what he wants to do, and decide how to do it. The data required to estimate system acquisition costs for a long-range planning study can be substantially less than those needed to prepare an independent cost estimate for contract negotiation. In the former, total equipment costs may suffice; in the latter, costs must be collected at the level of detail in which the contract is to be negotiated. For major items, this means a functional breakout, e.g., direct labor, materials, engineering, and tooling. One could postulate problems requiring even a greater amount of detail. Suppose, for example, that two similar hardware items had substantially different costs. Only by examining the cost detail could this difference be explained.

In performing this initial appraisal of the job, the analyst will be aided by a thorough knowledge of the kind of equipment with which he will be dealing--its characteristics, the state of its technology, and the available sample. With this knowledge he can determine the kinds of data that are required and that are available for what he wants to do, where the data are located, and the kinds of adjustments that may be required to make the collected data base consistent and comparable. Only after the problem has been given this general consideration should the task of data collection begin. All too often large amounts of data are collected with little thought about use. The result is that some portion may be unnecessary, unusable, or not completely understood. Data collection is generally the most troublesome and time-consuming part of cost analysis. Consequently, careful planning in this phase of the overall effort is well worthwhile.

- a. Historical Data. To develop a cost-estimating procedure, at least three different types of historical data are required. First, there are the resource data, usually in the form of expenditures and labor hours. It is customary to apply the work cost to both, and that practice is followed throughout this text. A second type of data describes the possible cost-explanatory elements; for hardware such as aircraft and missiles this means performance and physical characteristics. The third type is program data, i.e., information related to the development and production history of past hardware programs.
- b. Resource Data. Resource data are generally classified under end-item categories or functional categories. An example of the former in various possible levels of detail are system, subsystem, component, and part. The functional cost categories, such as engineering, tooling, manufacturing,

quality control, purchased equipment, are usually broken down into cost elements--labor, material, overhead, and other direct charges. The data source is the contractor's plant. Generally, the accounting systems will vary from one company to another, and the amount of detail is immense. A typical airframe company, for example, sets up the production process on the basis of a number of different jobs or stations, each identified by a number or symbol. All manufacturing direct labor and material (depending on the type of cost-accounting system) expended on a given job is recorded on a job order or, as is becoming increasingly more common, fed directly into a computer. When such a system is used, the actual hours incurred for every operation are available to management; and these costs can be aggregated as they are needed. Manufacturing costs of this type can be attributed to a lot or often to a single unit. (Some categories of cost are not identifiable by lot or unit, e.g., tooling and engineering.) But since contractors organize their work differently, different job orders will be used. This means that data at more detailed levels may vary from contractor to contractor and may not be comparable. Also, detailed information of this kind is unnecessary for most Government analysis and should rarely be sought.

If there were a need to estimate in more detail, the data required would increase by at least an order of magnitude, and data processing equipment would become a necessity. When to incorporate automatic data processing techniques into the data collection effort is determined primarily by the volume of data to be handled. The trend in the aerospace industry is to rely more and more on computers for internal data needs, and for some purposes data have been provided to the Government on punched cards or magnetic tape. Thus, there are no technical reasons why cost data could not be obtained in this form should it be more convenient to the cost analyst but, as mentioned earlier, there are good reasons not to use excessive detail even if it is readily available: Expense increases and accuracy is unlikely to improve.

Theoretical considerations aside, estimating techniques must be based on whatever resource data the analyst can find, and in the past the availability of data has varied from one kind of equipment to another. To illustrate, aircraft airframe estimating procedures tend to be different from those developed for other types of equipment. An airframe model may contain all of the following categories:

- o Initial and sustaining engineering.
- o Flight test operations.
- o Initial and sustaining tooling.
- o Manufacturing labor.
- o Manufacturing material.
- o Quality control.

Such a list of cost categories is desirable for all hardware estimating, but because of data limitations, present procedures for engines often cover only two phases of the procurement cost, development and production, and installed airborne equipment procedures only one, procurement cost to the Government. The CIR should expand these possibilities in the future.

- b. Physical and Performance Characteristics. Information about the physical and performance characteristics of aircraft and missile and space systems is just as important as resource data. Data collection in this area can be time-consuming, particularly since it is not often clear in advance what data will be required. The goal, of course, is to obtain a list of those characteristics that best explain differences in cost. Weight is a commonly used explanatory variable for aircraft airframes. One estimating procedure for aircraft uses all of the following:*

- o Maximum speed at optimal altitude.
- o Maximum speed at sea level.
- o Year of first delivery.
- o Total airframe weight.

* Planning Research Corporation, Methods of Estimating Fixed-wing Airframe Costs, Vol. I (Revised), PRC R547A, Los Angeles, April 1967.

- o Increase in airframe weight from unit 1 to unit n.
- o Weight of installed equipment.
- o Engine weight.
- o Electronics complexity factor.

In addition, the following characteristics were considered for inclusion as part of the estimating procedure, although they were not used:

- o Maximum rate of climb.
- o Maximum wing loading.
- o Empty weight.
- o Maximum altitude.
- o Design load factor.
- o Maximum range.
- o Maximum payload.

At the outset of a study undertaken to develop an estimating relationship for aircraft cost, the cost analyst would not know which of all these characteristics would provide the best explanation of variations among the cost of different aircraft; he would of necessity try to be as comprehensive as possible. An analyst who is familiar with the type of hardware under study will have some idea of the most likely candidates, but he will generally consider more characteristics than will eventually be used.

- c. Program Data. A third type of essential data is drawn from the development and production history of hardware items. The acceptance date of the item, the significant milestones in the development program, the production rates, and the occurrence of major and minor modifications in production--all such information can contribute to the development of cost-estimating relationships. The list of explanatory variables discussed in the previous section includes year of first delivery and increase in airframe weight from unit 1 to unit n, information that would be included in the category program data.

An airframe typically changes in weight during both development and production as a result of engineering changes. For example, the weight of the F-4D varied as follows:

<u>Cumulative Plane Number</u>	<u>Airframe Unit Weight (lb)</u>
1-11	8456
12-186	8941
187-241	8541
242-419	9193

Since labor hours are commonly associated with weight to obtain hours-per-pound factors, it is important to obtain weights applicable to each production lot if airframe weights by unit are not available.

The need for other kinds of program data will be clarified under the discussion on data adjustment. To cite one example here, the year in which expenditures occur must be known to adjust cost data for price level changes. (This is the reason for at least one CIR submission annually.) A certain amount of program data cannot be specified with this degree of precision nor can the use of these data be foretold, but the information is important nonetheless. It is what might be called background information--data on other activities in the contractor's plant at the time a particular hardware item is being built; unusual problems the contractor may be encountering; attempts to compress or stretch out the program; and inefficiencies that are noted. This information may be useful in explaining those factors that appear to be aberrations when the resource data are compared with those from other development and production programs. In addition, a history of a contractor's overhead, general and administrative costs, and labor rates is useful for analyzing and predicting costs.

2. DATA ADJUSTMENT.

To be useful to the cost analyst, data must be consistent and comparable, and in most cases the data as collected are neither. Hence, before estimating procedures can be derived, an adjustment must be made for definitional differences, production quantity differences, yearly price changes, and so on. The more common adjustments are examined in this section. It is by no means an exhaustive treatment of the subject: The list of possible adjustments is long and many of them will apply only in a very small number of cases. Also, evidence on certain types of adjustments (for contractor efficiency, for contract type, for program stretch-out) consists largely of opinion rather than hard data. While the cost analyst may allude to such adjustments, the research necessary to treat them in some definitive way has not yet been done.

- a. Definitional Differences. Different contractor accounting practices and make or buy arrangements are primary reasons why adjustment of the basic cost data is generally necessary. Companies record their costs in different ways. Often they are required to report costs to the Government by categories that differ from those used internally. Also, Government categories change from time to time. Because of these definitional differences, one of the first steps in cost analysis is to state the definition that is being used and to adjust all data to this definition. With the inception of the CIR, a standard set of definitions for airframes has been established for use throughout the DOD. A primary purpose of the CIR is to overcome the problem of definitional differences in hardware cost data. For the next few years, however, most data will antedate the CIR and some adjustment will be required.

As an example of what may be expected, a cost analyst may be examining data from a sample of 10 hardware items and discover that the cost category Quality Control is missing for some of the earlier items. He may conclude that no quality control was exercised in the 1950s or that this function is included in another cost element. The latter assumption is correct. Traditionally, Quality Control was carried in the burden account, and it was only in the late 1950s that it began to appear (at the request of the DOD) as a separate element. Hence, to use cost data on equipment built prior to this change requires converting a portion of overhead cost to Quality Control.

A more current example involves Planning, which in the CIR definition is included in Tooling. Planning consists of two components--tool planning and production planning. A company may put the first in Tooling and the second in Manufacturing. Other practices are to include tool planning in Engineering, to put all planning in Manufacturing, or to include a portion in Overhead.

Table 1 illustrates this problem more concretely. A slightly abbreviated version of the CIR list of cost elements appears on the left; on the right, the cost elements used by a large aerospace company and the nonrecurring costs of a proposed airframe. The lists are different and, as shown by Table 2, a simple rearrangement of the contractor cost elements does not solve the adjustment problem. Four of the contractor cost elements remain: Developmental Material (\$2.6 million), Outside Projection (\$70 thousand), Other Direct Charges (\$2.7 million), and Manufacturing Overhead (\$28.94 million). These are not trivial adjustments: These four elements can amount to well over half the total cost of a large production contract. Developmental Material presumably would be split between Engineering Material and Manufacturing Material; Other Direct Charges would have to be allocated among Engineering, Tooling, Quality Control, and Manufacturing; and part of Manufacturing Overhead would be apportioned to Tooling Overhead and Quality Control Overhead. In each of these instances, the contractor who furnished the CIR information would be able to make the necessary adjustments from his own accounting records. Outside Production costs, although small in this example, may constitute 30 to 40 percent of the total cost of an airframe in some cases. When this happens, the labor hours and material costs incurred by the prime contractor fall far short of the total required to build an airplane; a method of arriving at a total number must be devised to permit the data to be analyzed on a comparable basis, i.e., on an equivalent 100-percent inplant basis. Ordinarily, the contractor would have a detailed breakout of costs only for subcontractors on cost-reimbursable contracts, and other Outside Production costs would have to be allocated to the specific categories. Production labor hours incurred out of plant, for example, are often estimated on the basis of the weight of that portion of the airframe being built out of plant. In using historical data, the analyst may be in a similar position: When the amounts involved are large, he should be guided by whatever information the contractor can provide.

- b. Physical and Performance Considerations. A problem that resembles the one discussed above is the need for consistency in definitions of physical and performance characteristics. For example, speed can be defined in many ways--maximum speed at optimal altitude, true speed, equivalent speed, indicated speed. All of these defining terms differ in exact meaning and value. The weight of an aircraft or missile depends on what is included. Gross weight, empty weight, and airframe unit weight apply to aircraft, but each of these terms also differs in exact meaning and value. Some agencies include sweep volume in their definition of the physical volume of an aircraft fire control system; others exclude it. Differences such as these can lead an analyst unfamiliar with

Table 1.

ILLUSTRATIVE COMPARISON OF CIR AND AIRFRAME CONTRACTOR COST ELEMENTS

CIR Cost Element	Cost Element	Airframe Contractor	
			Nonrecurring Costs (\$ thousands)
Engineering	Engineering		8,600
Direct labor			
Overhead	Manufacturing		
Material	Developmental		
Other direct charges	direct labor		2,500
	Tooling direct		
Tooling	labor		11,600
Direct labor	Production direct		
Overhead	labor		850
Materials and purchased tools	Developmental		
Other direct charges	material		2,600
	Tooling material		2,600
Quality Control	Production material		500
Direct labor	Purchased equipment		5
Overhead	Outside production		70
Other direct charges			
	Inspection		620
Manufacturing			
Direct labor	Other Direct Charges		2,700
Overhead			
Materials and purchased parts	Overhead		
Other direct charges	Engineering		10,200
	Manufacturing		28,940
Purchased Equipment			
Material Overhead			

Table 2.

AIRFRAME CONTRACTOR COST ELEMENTS ARRANGED IN CIR FORMAT

CIR Cost Element	Cost Element	Airframe Contractor	
			Nonrecurring Costs (\$ thousands)
Engineering	Engineering		8,600
Direct labor	Engineering Overhead		10,200
Overhead			—
Material			—
Other direct charges			—
Tooling			
Direct labor	Tooling direct labor		11,600
Overhead			—
Materials and purchased tools	Tooling material		2,600
Other direct charges			—
Quality Control			
Direct labor	Inspection		620
Overhead			—
Other direct charges			—
Manufacturing			
Direct labor	Developmental direct labor		2,500
	Production direct labor		850
			—
Overhead	Production material		500
Materials and purchased parts			—
Other direct charges			—
Purchased Equipment	Purchased equipment		5
Material Overhead			—

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the equipment to use inconsistent or varying values inadvertently. When data are being collected from a variety of sources, an understanding of the terms used to describe physical and performance characteristics is at least as important as an understanding of the content of the various cost elements.

- c. Nonrecurring and Recurring Costs. Another problem that involves questions of definition concerns nonrecurring and recurring costs. Recurring costs are a function of the number of items produced; nonrecurring costs are not. Thus, for estimating purposes it is useful to distinguish between the two, and the CIR provides for this distinction. Unfortunately, historical cost data frequently show such cost elements as nonrecurring and recurring engineering hours as an accumulated item in the initial contract. Various analytical techniques have been developed for dividing the total into its two components synthetically, but it is not clear at this time whether the nonrecurring costs that are obtained by ex post facto methods will be comparable with those reported in the CIR. The CIR instructions state:

it is preferable to identify the point of segregation between nonrecurring and recurring engineering costs as a specific event or point in time. Ideally, the event used would be the point at which "design freeze" takes place as a result of a formal test or inspection, and after which formal Engineering Change Proposal (ECP) procedures must be followed to change design. If no reasonable event can be specified for this purpose, then all engineering costs incurred up to the date of 90 percent engineering drawing release may be used.*

Although it would be premature to consider the kinds of adjustments needed before a body of CIR data exists, splicing historical data to CIR data may also involve adjustments.

A more subtle problem arises when nonrecurring costs on one product are combined with recurring costs on another, i.e., when the contractor is allowed to fund development work on new products by charging it off as an operating expense against current production. This practice is especially prevalent in the aircraft engine industry. Separation of the nonrecurring and recurring costs means an adjustment of the production costs shown in contract or audit documents to exclude any amortization of development. The nonrecurring expense that has been amortized can then be attributed to the item for which it was incurred. Such an adjustment can only be accomplished in cooperation with the accounting department of the companies that are involved. It would not be necessary, of course, for equipment on which CIR data are available.

- d. Price-level Changes. Figure 1 shows the change in average hourly earnings of production workers on manufacturing payrolls from 1920 to 1965. Although these earnings declined slightly during the early 1920s and again during the Depression, the trend has been steadily upward since 1934. The

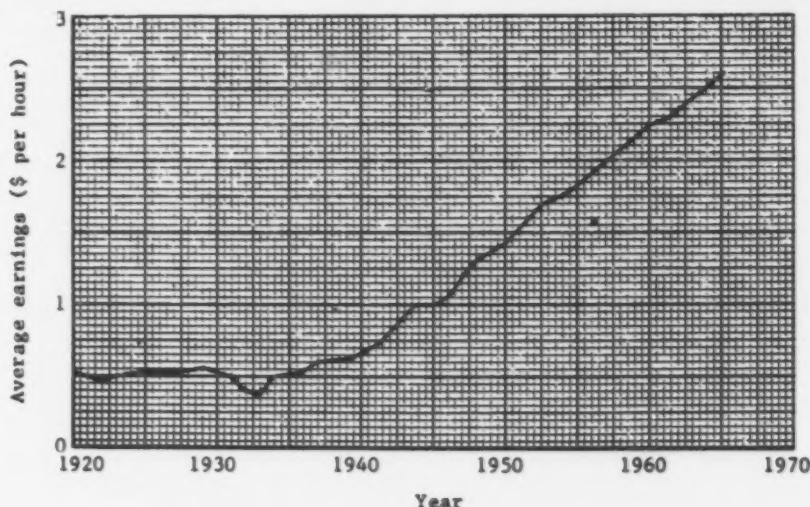


Figure 1. Change in Hourly Earnings

*U.S. Department of Defense, Cost Information Report (CIR) for Aircraft, Missile, and Space Systems, Budget Bureau No. 22-R2-J, Washington, D.C., April 21, 1966, p. 43.

hourly wage rate has increased by a factor of 4.75 over a 45-year period; in other words, a manufacturer paid \$4.75 for labor in 1965 that would have cost him \$1.00 in 1920. The implication for equipment cost is clear. If the labor component of an automobile cost \$500 in 1920, the cost for the same car today would be something over \$2000; however, the hours required in 1965 would be less because of increased productivity.

The relevance of these observations to the subject of data adjustment is that the manufacturing date of the different hardware items in a sample are normally spread over a period perhaps as long as 10 to 15 years. To compare a missile built in 1955 when labor cost about \$2.35 per hour with a missile built 10 years later when the labor rate had increased to over \$3.35 per hour, requires that the labor cost of both be adjusted to a common base. (This problem is obviated by dealing in hours rather than dollars, but an adjustment would still be needed for raw material and purchased parts.) Adjustments are made by means of a price index constructed from a time-series of data in which 1 year is selected as the base and the value for that year expressed as 100. The other years are then expressed as percentages of this base. The hourly earnings from 1950 to 1960 for production workers could be converted to an index using any of the years as the base; in Table 3, 1950 and 1960 have both been used as base years.

Table 3.

AVERAGE HOURLY EARNINGS INDEX

Year	Average Hourly Earnings (\$)	Index with 1950 as Base Year	Index with 1960 as Base Year
1950	1.44	100	64
1951	1.56	108	69
1952	1.65	115	73
1953	1.74	121	77
1954	1.78	124	79
1955	1.86	129	82
1956	1.95	135	86
1957	2.05	142	91
1958	2.11	147	93
1959	2.19	152	97
1960	2.26	157	100

SOURCE: U.S. Department of Labor, Employment and Earnings Statistics for the United States, 1909-66, Bulletin No. 11312-4, Washington, D.C., October 1966.

The information needed to construct a labor index is available in the Bureau of Labor Statistics (BLS) monthly publication Employment and Earnings, and Table 4 presents indexes based on this source. Changes in materials costs are available in another BLS monthly publication, Wholesale Prices and Price Indexes. These indexes can be used to develop a materials price index for a given type of equipment by selecting from the commodity groups in the Wholesale Price Index a list of materials representative of those used in constructing the equipment; these materials are then weighted according to estimates of the value of each in fabricating the equipment. A composite aircraft raw-materials index might be based on the following materials and weights:

Finished steel	.02
Stainless steel sheet	.04
Titanium sponge	.07
Aluminum sheet	.29
Aluminum rod	.11
Aluminum extrusions	.20
Wire and cable	.12
Rivets, nuts, bolts	.15

Table 4.

LABOR PRICE INDEXES

Year	Aircraft	Aircraft Engines and Engine Parts	Other Aircraft Parts and Equipment	Motor Vehicles and Equipment	Electrical Equipment and Supplies	Ship and Boat Building
1952	.59	.61	na ^a	.61	.64	.62
1953	.63	.63	na	.64	.67	.67
1954	.66	.65	na	.66	.69	.68
1955	.69	.67	na	.69	.71	.70
1956	.72	.71	na	.70	.76	.74
1957	.75	.74	na	.74	.79	.79
1958	.80	.79	.79	.76	.82	.82
1959	.84	.83	.83	.81	.85	.85
1960	.86	.86	.86	.84	.88	.88
1961	.88	.89	.88	.86	.91	.93
1962	.91	.92	.91	.90	.93	.95
1963	.94	.94	.94	.93	.95	.99
1964	.95	.97	.97	.96	.97	1.00
1965	1.00	1.00	1.00	1.00	1.00	1.00

^aNot available for years prior to 1958. For the years 1952-1957, the labor price index for aircraft should be used.

For any given year a price index for each of these is obtained and a composite index constructed by summing the individual index numbers multiplied by the weightings as shown in Table 5. Weights in an index need to be updated from time to time to reflect changing technology; it may be that those shown in Table 5 are applicable only to current aircraft. Table 5 merely illustrates the principle of deriving a composite index; the reader who wishes to pursue the matter will find index numbers discussed in textbooks on economic statistics.* Another type of composite index can be derived in the manner illustrated in Table 4 with the labor and material elements weighted according to the pattern that has been found to exist in the past (e.g., labor, 80 percent; materials, 20 percent). Overhead, which is a mixture of indirect labor, materials, and items such as rent, utilities, taxes, and fringe benefits, is adjusted in most cases by the same percentage as direct labor. To decide whether a different adjustment factor should be used, it would be necessary to examine each of these components.

Table 5.

AIRCRAFT RAW-MATERIALS INDEX

Commodity	1967 Index Number ^a	Weight	Index Number x Weight
Finished steel	105.8	.02	2.12
Stainless steel sheet	108.0	.04	4.32
Titanium sponge	60.3	.07	4.22
Aluminum sheet	99.8	.29	28.94
Aluminum rod	110.4	.11	12.14
Aluminum extrusions	75.6	.20	15.12
Wire and cable	126.0	.12	15.12
Rivets, nuts, bolts	133.2	.15	19.98
Composite index number	101.96		

^a1957-1959 = 100.

*See, for example, W.A. Spurr, L.S. Kellogg, and J.H. Smith, Business and Economic Statistics, rev. ed., Richard D. Irwin, Inc., Homewood, Illinois, 1961. It is important to recognize the differences in indexes that may result from weighting by base year or a given year, i.e., Laspeyres' or Paasche's index. These are also discussed in textbooks on economic statistics.

The adjustment of costs for yearly price changes is not always as straightforward as the foregoing discussion may imply. One problem is that price indexes are inherently inexact and their use, while necessary, can introduce errors into the data. The average hourly earnings for all aircraft production workers may increase by \$.05 in a given year, but at any particular company they will increase more or less than that amount. Use of the average number to adjust the data for a given company may bias the data up or down. Also, for many specialized items of equipment, a good published price index does not exist. In fact, the usual indexes are oriented toward the civilian economy and may be misleading, i.e., they may understate the change experienced in defense and space industries. The United States, with many other countries, furnishes the Office of Economic Cooperation and Development in Paris with an index applicable to Government defense expenditures in general. This index, shown in Table 6 for 1952-1964, is a useful reference when detailed index numbers seem questionable or are non-existent.

Table 6.

DEFENSE EXPENDITURES INDEX, 1952-1954

<u>Year</u>	<u>Index Number</u>	<u>Year</u>	<u>Index Number</u>
1952	84	1959	102
1953	83	1960	104
1954	84	1961	105
1955	88	1962	106
1956	93	1963	108
1957	97	1964	113
1958	100		

Another problem is that of identifying the years in which expenditures occur when the only data available show total contract cost. Production and cash flow may have been spread out over a period of several years, and in principle the costs should be adjusted for each year separately. Although the CIR will provide the information needed to do this in the future, this information may be unavailable today and some reasonable approximation of the expenditure pattern must suffice.

One method of obtaining this approximation is to use a percent-of-cost versus percent-of-time curve of the type illustrated in Figure 2. These curves are developed from historical data on a number of programs involving the same kind of hardware--large ballistic missiles in this case--and can be used to break total research and development or total production cost into annual expenditures. For example, to determine the annual expenditures in a 5-year R&D program amounting to a total of \$50 million the following percentages would be obtained from the R&D curve of Figure 2:

<u>Time</u>	<u>Expenditures</u>
20	5.5
40	23.0
60	65.0
80	92.0
100	100.0

These percentages are cumulative, of course, so the annual percentages and the amount they represent would be:

<u>Year</u>	<u>Expenditures</u>	
	<u>Percent</u>	<u>\$ Millions</u>
1	5.5	2.75
2	17.5	8.75
3	42.0	21.00
4	27.0	13.50
5	8.0	4.00

In the production phase, a technique that can be used is to develop lag factors by examining delivery schedules and production lead times. Costs are then lagged behind delivery dates by some reasonable factor.

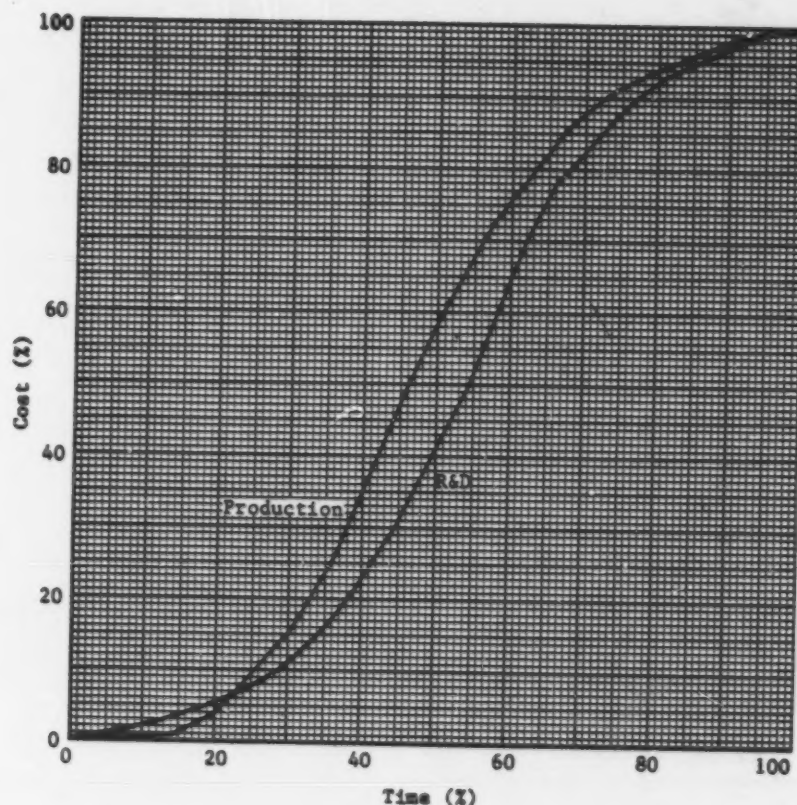


Figure 2. Percent-of-Cost Versus Percent-of-Time Curves

A more fundamental question than any of those raised above is whether yearly price changes should be made at all. It is sometimes argued that the upward trend in wage rates has been accompanied by a parallel trend in the output per employee or productivity rate. This argument implies that there has been little change in the real costs of aerospace equipment because increases in wages and materials cost have been offset by a decrease in the number of employees required per dollar of output. However, the real dollar output per man is difficult to measure in an industry in which continual change rather than standardization is the rule. Certainly the growth in productivity is not uniform for aircraft, missiles, ships, and tanks, and to develop a productivity index for each would be a difficult and contentious task. Present practice, therefore, is to apply the price-level adjustment factors to obtain constant dollars and, at the same time, to remain alert to inequities that may be introduced by following this procedure. As an illustration of the significance of price-level adjustments, Figure 3 shows the effect of adjusting production costs incurred over the period 1959-1965 (open circles) to 1962 dollars (closed circles). Both the level of cost and the slope of the curve change as a result of the price-level adjustment. (In this example a crossover occurs because the year 1962 has been selected as a base for adjustment.)

- e. Cost-Quantity Adjustments. The cost-quantity relationship, discussed at length in Chapter 5, is usually known in the aerospace industry as the learning curve. The cost-quantity relationship may be defined in brief as follows: Each time that the total quantity of items produced doubles, the cost per item is reduced to some constant percentage of its previous value. Whether or not this particular formulation is accepted, the fact remains that, for most production processes, costs are invariably a function of quantity: As a number of items produced increases, cost normally decreases. Thus, in speaking of cost, it is essential that a given quantity be associated with that cost. An equipment item can be said to cost \$100,000, \$80,000, \$64,000, or \$51,200, and all of these numbers will be correct.

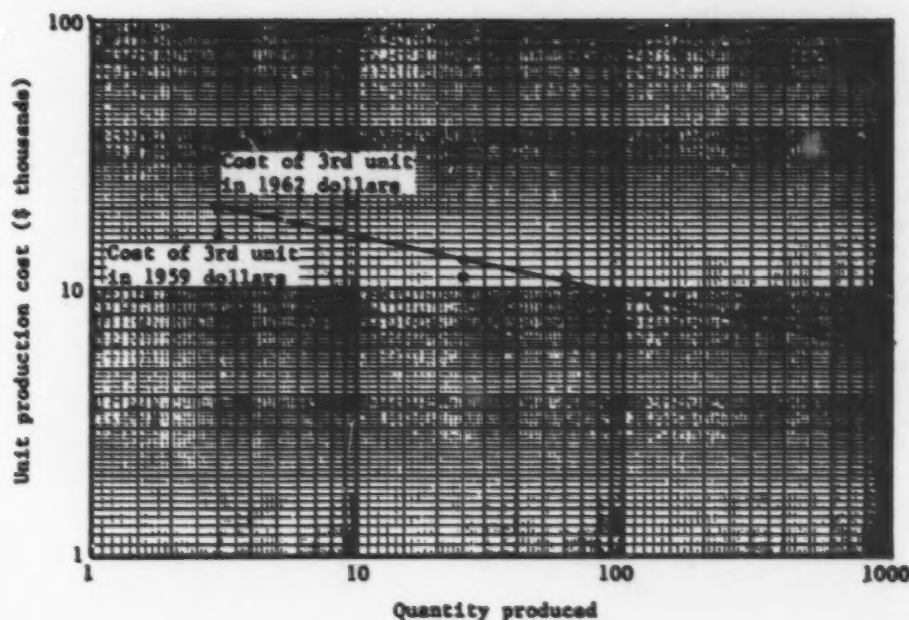


Figure 3. Effect of Adjustment for Price-Level Changes

Which cost should be used by the cost analyst? The answer will depend on a number of factors; if his purpose is to compare one missile with another, the cumulative quantity must be the same for both missiles. The adjustment to a specific quantity is a simple matter if the slope of the learning curve is known or if it can be inferred from the data. Take, for example, the costs for three missiles:

Missile	Unit Number	Cost/Unit (\$)
A	50	1000
B	100	1000
C	200	1000

Although the cost is the same for each, the number of units is different. Thus, for a cost comparison, the units must be adjusted to a common quantity. If 100 is chosen and an 80-percent learning curve assumed for all three missiles, the adjusted costs will be as follows:

Missile	Unit Number	Cost/Unit (\$)
A	100	800
B	100	1000
C	100	1250

To project labor requirements for the 100th unit when only 50 units have been produced is somewhat uncertain, but to ignore the cost-quantity relationship will in most instances result in greater error than such a projection introduces. (The learning curve is most frequently depicted as a straight line on logarithmic scales as shown in Figure 3.)

- f. Other Possible Cost Adjustments. The lack of a way to adjust cost data for productivity changes over time is illustrative of the current situation in which more kinds of cost adjustments have been theorized than have been quantified. For example, it has been suggested that adjustment may be required because of differences in contract type (fixed-price, fixed-price-incentive, cost-plus-fixed-fee contracts) or differences in the type of procurement (competitive bidding or sole source). The hypothesis is that the type of contract or procurement procedure will bias costs up or down, but this hypothesis is difficult to substantiate.

Another question concerns manufacturing techniques. What are the effects of varying amounts of capital investment or capital improvement and of changes in manufacturing state of the art? A related question concerns the efficiency of the contractor. It may be surmised that Contractor A

has been a lower cost producer than Contractor B on similar items, but this is extremely difficult to prove. A low-cost producer may be one who, because of his geographical location, pays lower labor rates. Contractors in Fort Worth, Texas, and in Atlanta, Georgia, may have a considerable advantage in this regard over their competitors in Los Angeles and San Francisco, California, and in Seattle, Washington. Table 7 does not give a fair picture of comparative rates because differences among industries in the various cities tend to be more important than differences in location. But, for two cities as close together as Los Angeles and San Francisco, labor rates differ by 10 percent. Thus, although it might not be possible to adjust cost data on the basis of contractor efficiency, adjustments can be made for differences in location by using the specific area labor rates.

Table 7.

AVERAGE HOURLY EARNINGS OF PRODUCTION WORKERS
ON MANUFACTURING PAYROLLS, NOVEMBER 1965
(in dollars)

Atlanta	2.69
Boston	2.69
Chicago	2.91
Detroit	3.45
Los Angeles	3.04
New Orleans	2.72
New York	2.63
Philadelphia	2.79
St. Louis	2.96
San Francisco	3.35
Seattle	3.25

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Employment and Earnings, Washington, D.C., January 1966.

CHAPTER 13

STATISTICAL METHODS IN DEVELOPMENT OF ESTIMATING RELATIONSHIPS

Many estimating relationships are simple statements that indicate that the cost of a commodity is directly proportional to the weight, area, volume, or other physical characteristic of that commodity. These estimating relationships are simple averages; they are useful in a variety of situations and, because of their simplicity, they require little explanation. In this chapter, the statistical considerations involved in developing cost estimating relationships for advanced systems are examined. The emphasis is on the derivation of more complex relationships, i.e., equations that are able to reflect the influence on cost of more than one variable. The intent is to illustrate a general approach to the development of such relationships and to introduce basic concepts of statistical analysis. The emphasis is not on statistics per se; the basic statistical theory as well as the computational aspects involved in developing these relationships are included only to clarify practical considerations. Statistical analysis can help provide an understanding of factors that influence cost, but estimating relationships are no substitute for understanding; regression analysis, which will be discussed in this study, does not offer a quick and easy solution to all the problems of estimating cost, although it is extremely useful.

The outstanding characteristic of a cost factor is that the relationship between cost and the explanatory variable is direct and obvious; thus, cost per pound is widely used because of the generally satisfying thesis that as a ship, tank, airplane, or pressure vessel increases in weight it becomes more costly. Weight changes alone do not always adequately explain cost changes, however, and additional explanatory variables are often needed. The problem is to find these variables and their relationship to cost. The procedure is to decide what variables are logically or theoretically related to cost and then to look for patterns in the data that suggest a relationship between cost and the variables. Table 1 contains a set of data on cost and selected variables that can be analyzed for such patterns. The costs of 10 airborne radio communication sets are given with the weight, power output, and frequency of each. It is to be expected that cost would increase with weight or with power output. Frequency is also included because in the past higher and higher frequencies have been sought to increase communication capacity and, for a given power output, frequency sets have been more costly.

Table 1.

TEN AIRBORNE RADIO COMMUNICATION SETS

Cost (\$)	Weight (lb)	Power Output (w)	Frequency (MHz)
22,200	90	20	400
17,300	161	400	30
11,800	40	30	400
9,600	108	10	400
8,800	82	10	400
7,600	135	100	25
6,800	59	6	400
3,200	68	8	156
1,700	25	8	42
1,600	24	0.5	258

A graphic analysis of the data in Table 1 shows that cost is not a simple linear function of any of the three explanatory variables. Cost tends to increase with weight, but there are notable exceptions to the trend, as illustrated by the scatter diagram of Figure 1. Cost plotted against power output as shown in Figure 2 is even less promising, partly because the arithmetic scale does not enable an observer to distinguish among the points between .5 and 30 watts. The change from an arithmetic to a logarithmic scale shown in Figure 3 spreads the points in the low-power range and indicates that a trend may exist, but with a very wide scatter.

The wide scatter in Figure 3 is explained in part by recognizing the effect of frequency. In Figure 4, each point is identified by frequency class: High Frequency (HF), up to 30 MHz; Very High Frequency (VHF), 30 to 300 MHz; and Ultra High Frequency (UHF), above 300 MHz. A clearer relationship exists between cost and power output within each frequency class than exists for the whole sample scattered without regard to frequency. This suggests that the sample is not homogeneous. Each frequency band may constitute a separate sample, or possibly HF and VHF costs are on one level and UHF costs are on another.

At this point, it is not clear if any of the explanatory variables, either singly or in combination, will yield a useful estimating relationship, or if a single relationship can serve for all frequencies. To illustrate techniques that are commonly employed in deriving estimating relationships, assume that cost can

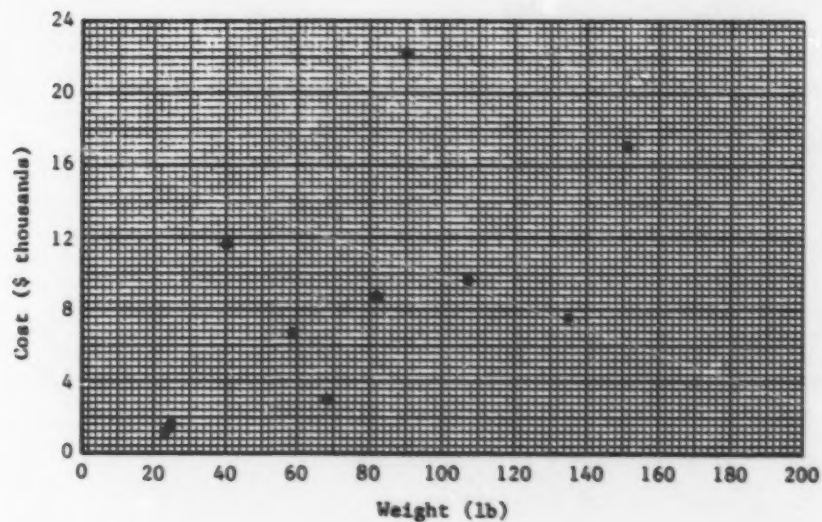


Figure 1. Scatter Diagram of Cost Versus Weight for Sample Data

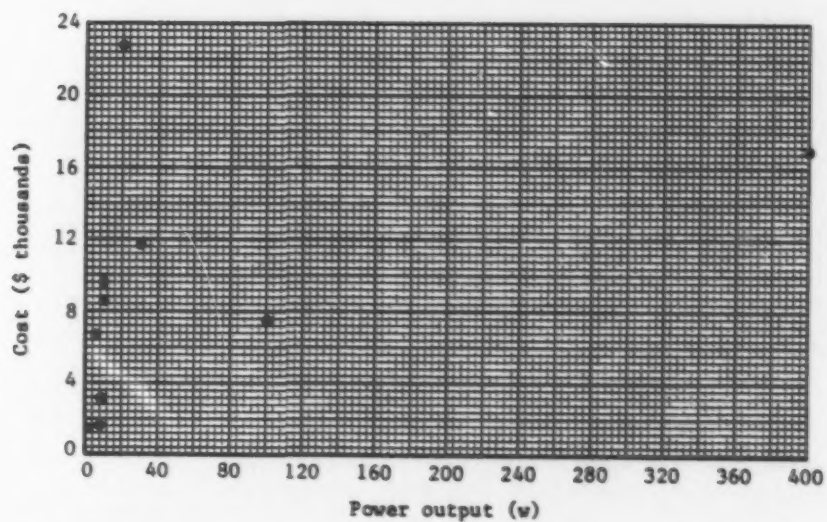


Figure 2. Scatter Diagram for Cost Versus Power Output for Sample Data

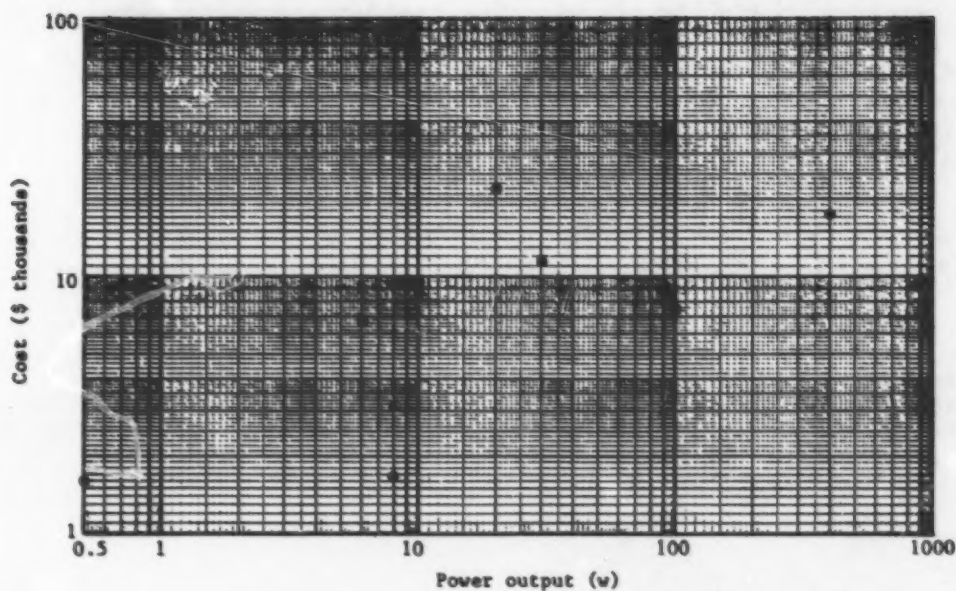


Figure 3. Scatter Diagram on Logarithmic Grid of Cost Versus Power Output for Sample Data

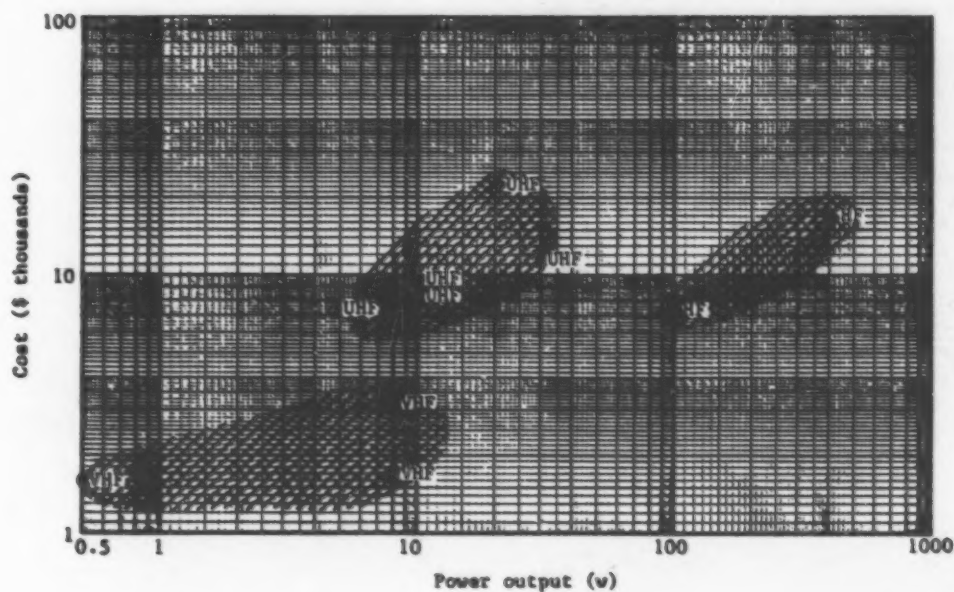


Figure 4. Identification by Frequency Class

be related to a single predictive variable--that of weight. The results of a linear normal simple regression model will then be examined. Later, several variables in a multiple regression analysis will be considered, and the problem of the apparent nonhomogeneous character of the sample illustrated in Figure 4 will be reexamined.

Regression has become a widely accepted tool for cost analysis, and it is frequently used to develop estimating relationships. The technique of regression analysis can be thought of as consisting of two distinct stages. The first is that of estimating the constant and coefficients of the equation, and the second is that of inferring the reliability and significance of the results of the estimate on the basis of assumed (and to a degree verifiable) properties possessed by the data and the results. Regression analysis as a technique is applicable only to the two stages performed together. Estimating coefficients or curve fitting is simply a mathematical exercise. Only when these estimating procedures are used as a basis for making statistical inferences can they be viewed as part of a regression analysis.

1. SIMPLE LINEAR REGRESSION.

The form of the relationships between cost and the explanatory variable(s) depends on the problem. It may reflect either an underlying physical law or a structural relationship. When no particular functional form is suspected, a simple (two-variable) linear model is frequently used to describe the relationship between two variables. In this case, the equation of the model is

$$y = a + bx, \quad (1)$$

where y is the dependent variable and x is the explanatory variable. The symbols a and b are the constant and coefficient, respectively, of the equation estimated from the data. Here y could represent the cost of a radio communication set and x could represent the weight. If it is assumed that b is greater than zero, the model indicates that heavier equipment will cost more than lighter equipment. When the values of a and b are known, it is possible to compute y (cost) for any given value of x (weight).

a. Least-Squares Estimating.

Given Eq. (1), the basic problem in the first phase of the regression analysis is to derive estimates of the parameters a and b . The standard procedure is the method of least-squares. The values of a and b are determined by the requirement that the sum of the squares of the deviations of the sample observations from the estimated line will be at a minimum. Symbolically, this minimum is expressed as

$$\min \sum_{i=1}^n (y_i - \hat{y}_i)^2, \quad (2)$$

where y_i is the i th observation and $\hat{y}_i$ is the value of y_i estimated from the equation

$$\hat{y}_i = \hat{a} + b\hat{x}_i. \quad (3)$$

The carets over $\hat{a}$ and $\hat{b}$ indicate that $\hat{a}$ and $\hat{b}$ are least-squares estimates of the true but unknown values of a and b . Thus $\hat{y}_i$ is the least-squares estimate of y_i and the term $(y_i - \hat{y}_i)$ indicates the difference between each observed y_i and between each corresponding estimated value $\hat{y}_i$. This is illustrated in Figure 5, which shows the actual (y) and estimated ($\hat{y}$) value of the dependent variable that corresponds to a specific value of the explanatory variable x . The line shown in Figure 5 is the line that represents Eq. (3). All of the estimated values of $\hat{y}_i$ fall on this line. The vertical distance from point A to point B is the difference between the actual value (y) and the estimated value ($\hat{y}$). The summation of all such differences that are squared (as illustrated in Eq. (2)) is the quantity to be minimized in estimating the line.

The minimum value for this sum is satisfied by substituting Eq. (3) in Eq. (2), taking the partial derivatives of Eq. (2) with respect to $\hat{a}$ and $\hat{b}$, and setting the results equal to zero. This process yields two equations that are called normal equations and that can be solved for $\hat{a}$ and $\hat{b}$:

$$\begin{aligned} \sum y &= n\hat{a} + \hat{b} \sum x, \\ \sum xy &= \hat{a} \sum x + \hat{b} \sum x^2, \end{aligned}$$

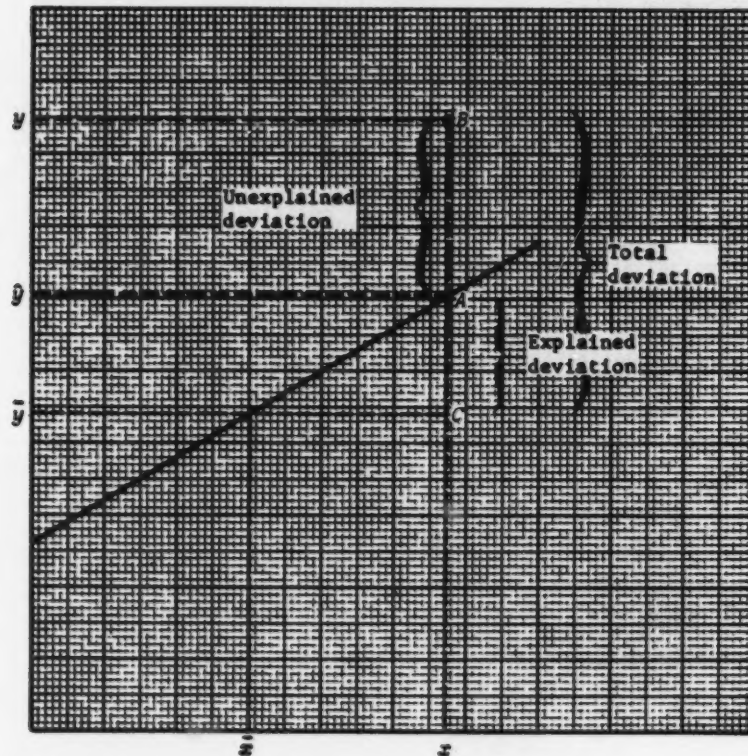


Figure 5. Deviation of Actual Value From Estimated Value and Sample Mean

where y = cost of airborne radio equipment in thousands of dollars,
 x = weight of airborne radio equipment in pounds,
 n = number of items in the sample,
 Σ = summation (e.g., Σy = the sum of all y 's).

Table 2 contains the numerical values and totals required to solve the normal equations when data from Table 1 are used. The costs are expressed in thousands of dollars. When the values from Table 2 are substituted in the normal equations, the following expressions are obtained for the sample data points ($n = 10$):

$$90.6 = 10a + 792b,$$

$$8739.4 = 792a + 81,540b.$$

Solved simultaneously, these equations give

$$\hat{a} = 2,477,$$

$$\hat{b} = .083,$$

and thus from Eq. (3)

$$\hat{y} = 2,477 + .083x. \quad (4)$$

The line represented by this equation is shown in Figure 6 as the solid line with the actual observations plotted as dots. The extent of the dispersion of the observations relates inversely to the usefulness of the line as a tool for estimating the values of y from the values of x . The greater the dispersion of observed values of y about the line, the less accurate the estimates that are based on the line are likely to be. The measure of the dispersion about the regression line is called the standard error of estimate (SE) of the equation and is shown by the dashed lines.

Table 2

DATA FOR REGRESSION ANALYSIS OF COST AND WEIGHT

x	y	x ²	xy
90	22.2	8,100	1,998.0
161	17.3	25,921	2,785.3
40	11.8	1,600	472.0
108	9.6	11,664	1,036.8
82	8.8	6,724	721.6
135	7.6	18,225	1,026.0
59	6.8	3,481	401.2
68	3.2	4,624	217.6
25	1.7	625	42.5
24	1.6	576	38.4
792	90.6	81,540	8,739.4

One measure of dispersion in a collection of data points is called the variance. The variance is defined as the sum of the squared distances to each of the data points from a central reference point divided by the degrees of freedom (df), which equal the number of independent bits of information contained in the sample. (In analyzing the data that are given in Table 1, the degrees of freedom equal $(n - 2)$; i.e., the number of observations n less the number of constraints, 1 each for a and b .)

In least-squares procedures, the central point of reference for calculating the variance of each variable is its sample mean, which causes the least-squares line to have the property of passing through the means of the variables used to estimate the line. This characteristic is shown in Figure 5; it can be verified by dividing both sides of the first normal equation by n , since the sample mean of any variable y is

$$\frac{\sum_{i=1}^n y_i}{n} = \bar{y}. \quad (5)$$

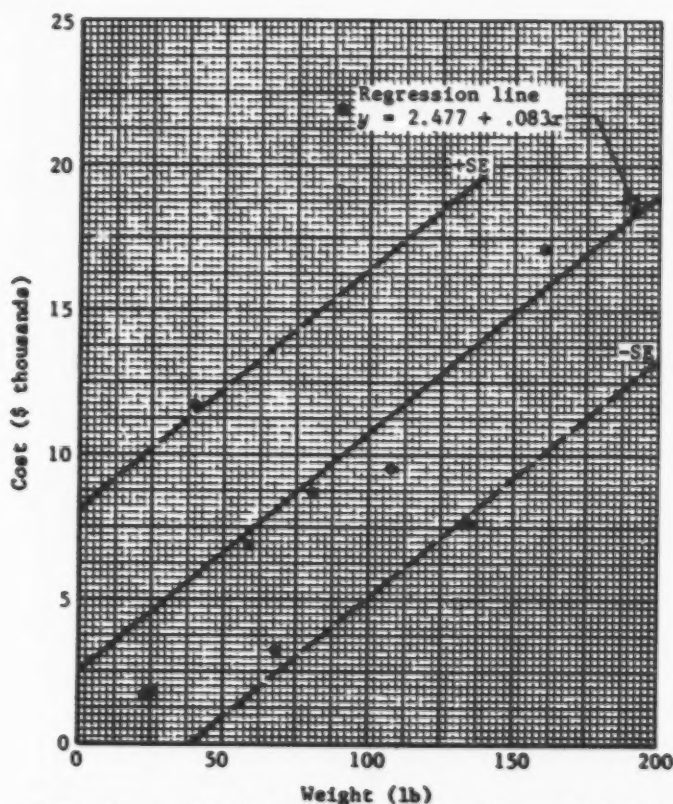


Figure 6. Regression Line and Standard Error of Estimate

By referring to Figure 5, it can be seen that the total distance from y_1 to $\bar{y}$ for any observation on y is the distance from C to B. The sum of all such distances squared and divided by the degrees of freedom is called the total variance of y :

$$\text{Total variance of } y = \sum \frac{(y_1 - \bar{y})^2}{n - 1}. \quad (6)$$

The distance from C to A indicates the amount of the total deviation of y from $\bar{y}$ which is explained by the estimating relationship. Consequently, the sum of the distances from $\bar{y}$ to the line, squared and divided by the degrees of freedom, is called the explained variance:

$$\text{Explained variance of } y = \sum \frac{(\hat{y}_1 - \bar{y})^2}{n - 2}. \quad (7)$$

The remaining distance from A to B is the residual or unexplained deviation from y_1 to $\bar{y}$, or the unexplained variance:

$$\text{Unexplained variance of } y = \sum \frac{(y_1 - \hat{y}_1)^2}{n - 2}. \quad (8)$$

The standard error of estimate is defined as the square root of the unexplained variance of y 's:

$$SE = \sqrt{\frac{\sum (y_1 - \hat{y}_1)^2}{n - 2}}. \quad (9)$$

For the equation $y = 2.477 + .083x$, the standard error of estimate is \$5,808. This value has been plotted above and below the regression line in Figure 6. The interpretation and significance of these results will be discussed in connection with the use of prediction intervals.

In comparing one SE with another, it is useful to compute a relative standard error of estimate. One such measure is the coefficient of variation (CV), which relates the SE to the mean of the sample y 's:

$$CV = \frac{SE}{\bar{y}}. \quad (10)$$

Continuing the analysis of the data in Table 1, the mean of the y 's is \$9,060. Therefore, the value of CV is

$$\frac{\$5,808}{\$9,060} = .641.$$

This value is high. Although the question of reliability of an estimating equation is relative to the context in which the equation is to be used, a value at least as small as 10 to 20 percent for the coefficient of variation is desirable.

The standard error of estimate gives a measure of the magnitude of the unexplained variance. Another related measure of dispersion is given by the coefficient of determination that shows the proportion of total variance accounted for by the estimating relationship:

$$\begin{aligned} r^2 = \text{Coefficient of determination} &= \frac{\text{Explained variance}}{\text{Total variance}} \\ &= 1 - \frac{\text{Unexplained variance}}{\text{Total variance}}. \end{aligned} \quad (11)$$

When all the observed points in the sample are on the least-squares line, the coefficient of determination equals 1 and there is no unexplained or residual variance. As the proportion of total variance that remains unexplained increases, the coefficient of determination approaches zero. The square root of the coefficient of determination is called the correlation coefficient.* Correlation has no substantive meaning unless both the dependent and explanatory variables are assumed to be normal random variables. The ordinary assumption in using regression analysis for developing estimating relationships is that only the dependent variable is random. Consequently, it is not considered good practice for the correlation coefficient to be used in documenting the results in this particular application of regression analysis. The inclusion of the correlation coefficient, however, causes no serious problem since it is simply the square root of the coefficient of determination. When analysts review the results, they can easily calculate the latter from the former. Since the coefficient of determination is always in the range between zero and one, its square root will always be larger, except at the boundary points of zero and one.

The coefficient of determination for Eq. (4) is .325, which is relatively low and further substantiates the evidence that weight alone is not a good predictor of the cost of airborne radio communication equipment.

- b. Statistical Inference. The standard error of estimate, the coefficient of variation, and the coefficient of determination indicate the degree of accuracy with which the estimating equation describes the sample observations. However, the analyst is primarily interested in using the estimating equation to predict costs among the population of items that the sample represents; the standard error of estimate and the coefficient of determination do not furnish a good measure of the reliability of the estimating equation for predictive purposes.

The problem of reliability raises other considerations. First, the question arises whether x and y are actually related in the manner indicated by the regression equation. A particular sample could show such a relationship out of pure chance when, in fact, none exists. Second, the regression equation obtained from the sample is one of a family that could be obtained from different samples within the same population. Finally, when the equation is used to estimate a value for y based on an x that is outside the range of the sample, the reliability of the estimate of y may be suspect because the estimated relationship may not hold beyond the sample range or because the x is a point from a different population rather than an extrapolation from the sample. An example of an extrapolation for which the relationship might not hold is that of an aircraft that is much larger than any in the sample. The problem of moving to a new population appears in a case in which an aircraft is to be constructed of titanium when the sample contains only aluminum aircraft. In the latter case, if a substitution of titanium for aluminum is expected to increase the cost, the estimating relationship developed from the aluminum sample may be used by an experienced analyst as an approximate indicator of the lower bound; however, adjustments based on such personal judgments are not a part of statistical theory.

Statistical inference may be used to answer the two questions that arise in connection with the problem of reliability. To decide whether x and y are actually related, test for statistical significance; to evaluate predictions, establish a prediction interval for the regression line. However, certain assumptions and conditions must be met before standard techniques of statistical inference and testing can be validly applied to least-squares results; namely, the data are assumed to be a sample taken from a larger population, which meet the following conditions:

1. The x values are nonrandom (fixed) variables.
2. The residual deviations are independent random variables with normal distributions.
3. The expected value of the distribution of each of these random variables is zero, and the unknown variance is the same for all values of x .

Under these assumptions, the hypothesized relationship between y and x becomes

$$y_i = a + bx_i + u_i, \quad (12)$$

where $i = (1, \dots, n)$,

u_i = the normally distributed random error terms with zero expected value and a common and unknown variance.

*Since total variance, Eq. (6), and the standard error, Eq (9), have been adjusted for degrees of freedom, the resulting correlation coefficient, the square root of Eq. (11), is also adjusted. Some computer programs do not adjust; the variance figures are then biased downward and the correlation coefficient will appear larger than in the unadjusted case. The practical implications of these adjustments is minimal except in extremely small sample cases. However, to fully understand the results, the analyst should know whether the total variance, standard error, and correlation coefficient are adjusted in any particular program or set of results. A discussion of adjustments for degrees of freedom is given M. J. B. Ezekiel and K. A. Fox, Methods of Correlation and Regression Analysis, 3d ed., John Wiley & Sons, Inc., New York, 1959, pp. 300-305.

Further, under these assumptions, the least-squares method produces unbiased maximum likelihood estimators. Standard statistical techniques can be applied to the least-squares results to test for significance and to make inferences about reliability and accuracy in a probabilistic sense.* A graphic illustration of these assumptions as they relate to the simple (two-variable) regression case is shown in Figure 7.

Although the subject of statistical testing is too complex to treat comprehensively here, the method of testing the significance of the relationship between x and y in the simple regression of Figure 6 will be examined briefly. Basically, the procedure involves establishing the null hypothesis that x and y are not related (i.e., that $b = 0$), and testing to determine whether the hypothesis should be rejected. The test that is commonly used for this purpose is known as the t -test because it uses the t -ratio, or ratio of a coefficient to its standard error. For this simple regression, the ratio is expressed as

$$t_b = \frac{\hat{b}}{s_b}, \quad (13)$$

where $\hat{b}$ = the estimated regression coefficient (from the equation $\hat{y} = \hat{a} + \hat{b}x$),

s_b = the standard error of b ,

$$s_b = \frac{SE}{\sqrt{\sum (x_i - \bar{x})^2}}$$

SE = the standard error of estimate as defined in Eq. (9).

The value of t_b for Eq. (4) is 1.96.

A standard table of t -ratios is required to use Eq. (13) to test the null hypothesis.** The relevant row is shown in Table 3. If the calculated value t_b falls below the appropriate value of t selected from this table, the null hypothesis that $b = 0$ would be accepted, and it would be concluded that b is, in fact, not significantly different from zero. The level of significance above each of the t -values indicates the probability that the calculated value could be as high strictly by chance as the values that are shown in the table. In other words, these levels of significance indicate the probability that the null hypothesis will be rejected when it is true.

Table 3
VALUES OF t -RATIOS FOR 8 DEGREES OF FREEDOM
(One-sided Test)

Degrees of Freedom	Level of Significance					
	.20	.15	.10	.05	.025	.01
.	t-Ratio					
8	.889	1.108	1.397	1.860	2.306	2.896

If there were evidence to justify the assumption that the sign of the coefficient could be only positive (or only negative) if it were different from zero, the level of significance associated with each t could be read directly from Table 3. However, the common practice in regression analysis is not to make this assumption, but to test as though the value of t (if it were different from zero) could be either positive or negative. Because of the symmetry of the distribution of the t -ratios, the level of significance for the two-sided test is twice the level of significance

*A more comprehensive statement of these assumptions and considerations is given in W. A. Spurr and C. P. Bonini, Statistical Analysis for Business Decisions, Richard D. Irwin, Inc., Homewood, Illinois, 1967, pp. 564-565; A. M. Mood, Introduction to the Theory of Statistics, McGraw-Hill Book Company, Inc., New York, 1950, pp. 152-154; and John Johnson, Econometric Methods, McGraw-Hill Book Company, Inc., New York, 1963, pp. 3-9.

**All of the Textbooks in the Bibliography to this chapter contain t -tables.

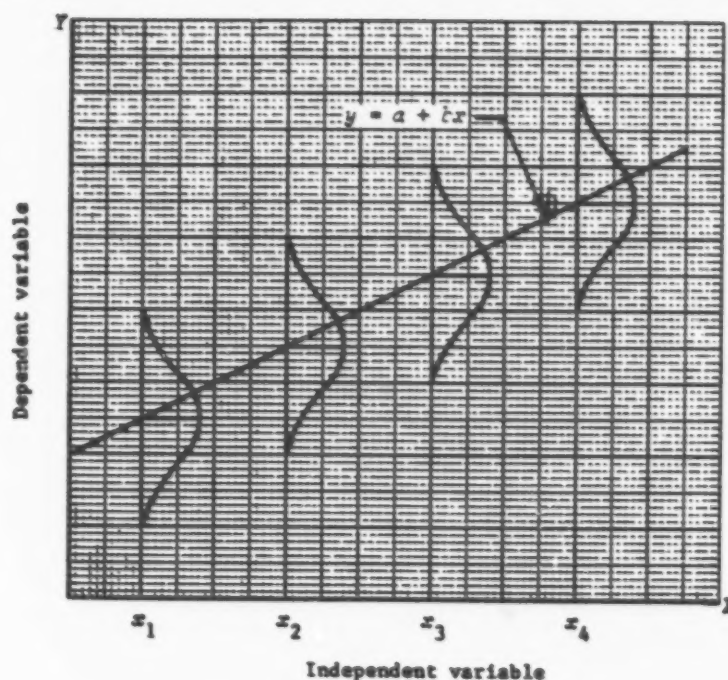


Figure 7. Simple Linear Population Regression Model

for the one-sided test. Thus, the levels of significance of the t -values shown in the table are only half the actual levels for the two-sided test. For example, the value 1.86 has a level of significance of .05. For the two-sided test, double this amount and read the level of significance as .10. In the two-sided test, the probability is 10 percent that the absolute value of t_b is as large as 1.86 when b is actually equal to zero. Since in the example $t_b = 1.96$, if the required level of probability for rejecting the null hypothesis when it is true is as high as 10 percent but no higher, the hypothesis that $b = 0$ is rejected, and the relationship is considered significant. On the other hand, if a .05 level of significance ($t = 2.306$) seems appropriate, the hypothesis must be accepted. In this case, the coefficient of x , and therefore the equation, is considered as not significant.*

The question at this point is, What should the level of significance be for rejecting the hypothesis? Unfortunately, no simple answer is possible. The values of .10, .05, and .01 are those that are most commonly used, but the analyst must make a decision based on the risk that is assumed when a true hypothesis is rejected.** For the purpose of this discussion, we will accept a value of .10 in testing significance and in establishing a prediction interval for the regression line.

- c. Prediction Intervals. The procedure for calculating the prediction interval for a simple regression is as follows. For a given value of the explanatory variable, say x , the estimating equation is used to obtain a predicted value of the dependent variable:

$$\hat{y} = \hat{a} + \hat{b}x. \quad (14)$$

The prediction interval puts a boundary around $\hat{y}$:

$$\hat{y} \pm A_{\epsilon/2}. \quad (15)$$

There is a certain level of confidence $(1 - \epsilon)$ that the cost of a set weighing x will be in that interval.

*A more comprehensive discussion of the use of statistical tests is given in W. A. Wallis and H. V. Roberts, Statistics, The Free Press, New York, 1963, pp. 399-402, 413-426.

**For further discussion, see W. A. Spurr, L. S. Kellogg, and J. H. Smith, Business and Economic Statistics, Richard D. Irwin, Inc., Homewood, Illinois, 1961, pp. 251-255.

Values for $\epsilon/2$ rather than ϵ are used since $\hat{y}$ is to be bounded on both sides. The values of ϵ can be divided by two since under the assumptions, the probability distribution about $\hat{y}$ is normal and therefore is symmetrical. In statistical terminology, a two-tailed t distribution for constructing the intervals is used.

In the case of simple regression, a $100(1 - \epsilon)$ -percent prediction interval for an estimated value of the dependent variable can be constructed as follows:

$$\hat{y} \pm A_{\epsilon/2}, \quad (16)$$

where

$$A_{\epsilon/2} = (SE)t_{\epsilon/2} \sqrt{\frac{n+1}{n} + \frac{(x - \bar{x})^2}{\sum(x_i - \bar{x})^2}}, \quad (17)$$

and where SE = the standard error of the estimating equation from which $\hat{y}$ was obtained,
 $t_{\epsilon/2}$ = the value obtained from a table of t -values for the $\epsilon/2$ significance level,
 n = the size of the sample,
 x = the specified value of the explanatory variable used as a basis for obtaining $\hat{y}$,
 $\bar{x}$ = the mean of the x 's in the sample,
 $\sum(x_i - \bar{x})^2$ = the sum of the squared deviations of the sample x 's from their sample mean.

When the estimating equation derived previously is used, the cost of a communications set weighing 100 lb is estimated at \$10,777. To establish around this value a 90-percent prediction interval (i.e., one with a 10-percent level of significance), the necessary data are

$$\begin{aligned} SE &= 5.808, \\ \epsilon &= 0.1, \\ \epsilon/2 &= 0.05, \\ t &= 1.86, \\ n &= 10, \\ df &= 8, \\ x &= 100 \text{ lb}, \\ \bar{x} &= 79.2 \text{ lb}, \\ \sum(x - \bar{x})^2 &= 18,813.6 \text{ lb.} \end{aligned}$$

By substituting these data in Eq. (17), solving for $A_{\epsilon/2}$, and multiplying by 1000, we obtain

$$A_{\epsilon/2} = \$11,447.$$

Therefore, for $x = 100$ lb, the 90-percent prediction intervals in dollars are

$$\hat{y} \pm A_{\epsilon/2} = \$10,777 \pm \$11,447.$$

The percentage $100(1 - \epsilon)$ is the confidence level of the prediction intervals, which means that if repeated observations on the cost of communications sets that weigh 100 lb were taken, $100(1 - \epsilon)$ percent of the time these observations would lie within the range set by the $100(1 - \epsilon)$ prediction intervals. This is the only sense in which a level of confidence can be associated with prediction intervals. It is erroneous to infer that there is a $100(1 - \epsilon)$ -percent probability that the actual value for any particular case will lie within the interval.

Further, prediction intervals are valid outside the range encompassed by the sample data that are used to generate the estimating relationship and the interval only if the estimating relationship is itself valid outside that range. For example, if there were occasion for the line to curve up or down or if a discontinuity in the form of a discrete jump in cost occurred for weights outside the sample range, this fact would not be reflected in the prediction interval. Thus, it must be clearly indicated when the intervals are used for estimates based on values outside the sample range.

This prediction interval procedure can be repeated for other values of x and the results plotted to obtain a 90-percent prediction interval band around the regression line, as shown in Figure 8. In this case, the 90-percent confidence region is fairly wide because of the relatively large standard error of this equation. The formula for the prediction interval is such that the width of the interval is sensitive to the size of the standard error; large standard errors indicate that much of the cost variation in the observed data is unexplained by the equation.

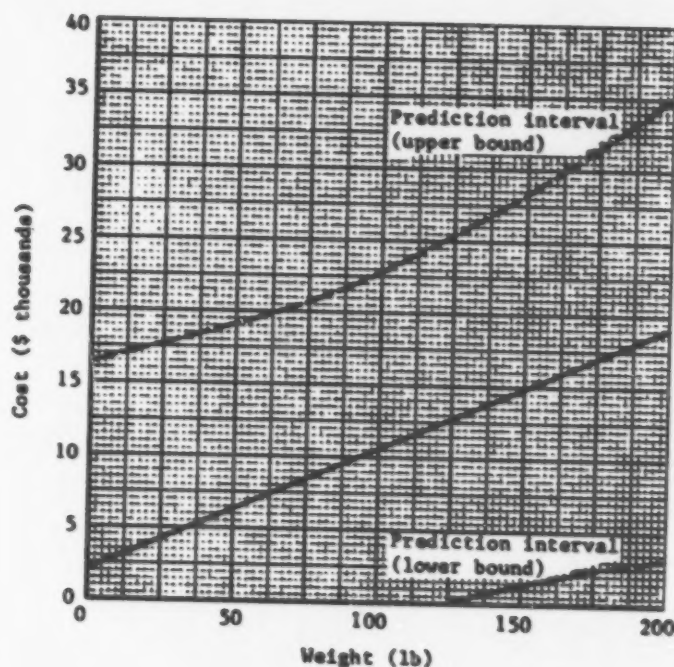


Figure 8. The 90-Percent Prediction Interval Band For Estimated Costs Based on Sample Data

The prediction interval becomes wider as values of x that are farther from the mean of the sample are selected. From Eq. (4), the prediction interval (multiplied by 1000) for the mean 79.2 lb is $\$9,051 \pm 411,329$; for $x = 200$ lb, the prediction interval is $\$19,077 \pm \$14,794$. In the latter case, the width of the interval is about 1.3 times the width for the mean weight. This change in the size of the prediction interval occurs because the formulas are derived to allow for the possibility that the estimated values of $\hat{a}$ and $\hat{b}$ differ from the true values of a and b . Such a situation can occur when the sample data contain chance fluctuations that prevent the data from reflecting the true relationship that exists in the total population or when there are not sufficient data in the sample.

Figure 9 illustrates the way in which errors in the estimates of $\hat{a}$ and $\hat{b}$ affect the accuracy of estimates. The solid line represents the true relation between x and y . The dashed line represents an equation in which the estimated values of $\hat{a}$ and $\hat{b}$ differ from the true values. The figure shows that the effect of these errors increases with movement toward the extreme ranges of x .

The width of the prediction interval is also sensitive to the level of confidence that is specified and to the number of degrees of freedom. That level was set at 90 percent (i.e., $\epsilon/2 = 0.05$). Suppose that only a 70-percent level of confidence is required ($\epsilon/2 = 0.15$). The only change in the inputs used in the previous calculations is the value of t . With a 90-percent level of confidence, $t_{.05} = 1.86$; with a 70-percent level, $t_{.15} = 1.11$. This change will make a difference in the width of the prediction interval. Since the level of confidence is lower, the prediction interval is narrower; for lower levels of confidence, the band will be even more narrow. For $\epsilon = .10$ and the degrees of freedom = 8, the value of $t_{\epsilon/2}$ is 1.86. If the degrees of freedom were 16, $t_{\epsilon/2}$ would be 1.746. Thus, if there are twice as many degrees of freedom for an equation with the same standard error, the prediction interval for $\epsilon = .10$ is smaller. However, the difference in prediction interval size because of differences in degrees of freedom is more significant for small samples than for large samples; the value of t for any given level of significance becomes almost constant for degrees of freedom over 30. For example, the smallest value of $t_{\epsilon/2}$ for $\epsilon = .10$ is 1.645.

Before concluding this chapter, there are two additional points to be made. First, even when the coefficient of determination r^2 is high, it is possible for the standard error of estimate to be large. This is explained by the fact that r^2 is based on a proportion and the standard error is based on an absolute quantity:

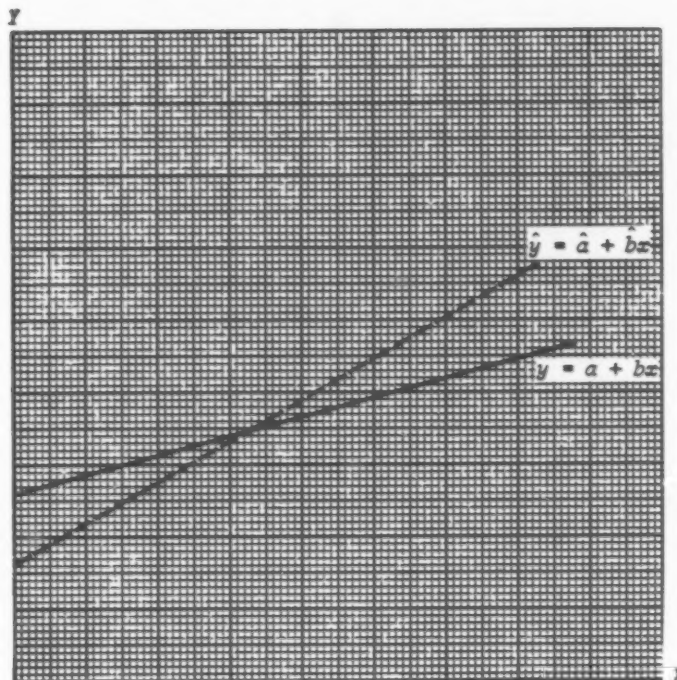


Figure 9. Effects of Estimating Errors On Accuracy of Predictions

$$r^2 = \frac{\text{Explained variance}}{\text{Total variance}}$$

$$SE = \sqrt{\text{Unexplained variance.}}$$

Thus, even if the explained variance represents a high fraction of the total variance, it is possible for the unexplained variance to be large relative to the estimated cost. This outcome would be indicated by the coefficient of variation.

Second, the statistical significance of regression relationships does not necessarily imply existence of a casual relationship. The following excerpt from an Institute of Defense Analyses (IDA) memorandum illustrates the importance of this distinction in cost analysis:*

Frequently during cost effectiveness studies, the distinction between a "causation" cost model and a "correlation" cost model is overlooked. A simple example will be used to illustrate the distinction between the two types of cost models and show how a sensitivity analysis performed with a correlation cost model, rather than a causation model, can lead to erroneous conclusions.

Example: Estimate the cost of assembling a piece of hardware. The assembly consists merely of bolting various elements together. The overwhelming majority of the cost of the assembly process is the salary paid to the men who do the bolting. Careful analysis of all the available cost data might yield a correlation cost model given by Equation 1.

$$C = a x w \quad (1)$$

where w is the total weight of all the bolts that go into the assembly,
 C is the cost of the assembly,
 a is a regression coefficient.

*Morris Zusman, "Use of Cost Models in Sensitivity Analysis and as a Design Aid," Institute of Defense Analyses, N-587(R), September 1968. In this discussion, the term correlation is used figuratively in the sense that it is statistically significant in explaining the amount of variance rather than in the sense that both the dependent and independent variables are random.

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By all of the various statistical measures of goodness of fit, Model 1 is a valid prediction equation.

The causation cost model is given by Equation 2.

$$C = k \times h \times n \quad (2)$$

where k is the hourly wages of the assemblers,
 h is the number of hours it takes to fasten and bolt,
 n is the number of bolts used in the final assembly,
 C is the cost of the assembly.

It should be noted that the correlation cost model and the causation cost model are interrelated by Equation 3.

$$w = B \times N \quad (3)$$

where B is the weight of a single bolt,
 w is the total weight of all of the bolts that go into the assembly.

Thus any design or sensitivity analysis performed on Equation 1, the correlation cost model, will lead to the correct results if Equation 3 is not violated. For example, an analyst would be correct in predicting that a cost reduction would occur if he reduced the weight of the fasteners used by using less fasteners. He would be incorrect if he predicted a cost reduction would occur if he reduced the weight of the fasteners by substituting aluminum for steel bolts while keeping the number of bolts constant. The reason that a substitution of aluminum for steel bolts would not reduce the cost, is because the underlying relationship between the number of bolts and the weight of the fasteners (Equation 3), which is the reason for the good cost weight relationship of the correlation model, has been violated.

In mathematical terms both a causation and a correlation cost model have the following properties.

$$\text{Cost} = f(\text{characteristics}) \quad (4)$$

But only a causation model can be manipulated as Equation 5.

$$\text{Characteristics} = f^{-1}(\text{cost}) \quad (5)$$

The problem of determining whether a cost model is a correlation or a causation model is, except for the trivially simple type of problem illustrated here, very difficult since all causation models can be transformed into correlation models. There exist no statistical tests to determine whether a model is a causation model or a correlation model.

The types of explanatory variables used in the cost model generally will give a good guide as to whether a model is a correlation model or a causation model. For example, weight as an explanatory variable in a cost model where the material cost did not dominate, would be a good indication that the cost model was a correlation model.

If the model is a correlation model and the analyst performs a sensitivity analysis, he runs the risk of violating the unknown underlying relationships between the correlation and causation models. If these underlying relationships are violated the sensitivity analysis will be erroneous.

This example illustrates that regression analysis is an aid to, and not a substitute for, experience and understanding.

2. CURVILINEAR ANALYSIS.

Until this point the analysis has been confined to a simple (one explanatory variable) linear regression. Although a cursory examination of the scatter diagram of cost versus weight illustrated in Figure 1 indicates that a linear relationship be adequate, it cannot be concluded definitely that a curvilinear relationship might not be preferable. These relationships can be examined by transforming the data to permit the relationships to be estimated using linear estimating techniques. The equation

$$y = a + bx^2 \quad (18)$$

can be estimated using the least-squares method by substituting x^2 for each x and solving the normal equations as before.

Another type of nonlinear relationship that is frequently used and that will be examined in discussing cost-quantity relationships in Chapter 5 is of the form

$$y = ax^b. \quad (19)$$

For this form, a logarithmic transformation of both variables is made to obtain an equation that is linear in the logarithms of the original variables:

$$\log y = \log a + b(\log x). \quad (20)$$

The regression analysis is then conducted in terms of the logarithms of the variables rather than in terms of the variables themselves. (Throughout this section, logarithms to the base 10 will be used.)*

However, to permit the standard techniques of statistical inference based on linear least-squares regression to be used, it is assumed that the dependent variable $\log y_i$ is linearly related to the independent variable $\log x_i$ and to the normally distributed random variable u_i by the equation

$$\log y_i = \log a + b \log x_i + u_i \quad (i = 1, \dots, n). \quad (21)$$

When antilogarithms are used, Eq. (21) is implicitly of the form

$$y = ax_i^b 10^{u_i}. \quad (22)$$

Because of this difference in form, statistics derived for Eq. (22) are not directly comparable with those derived for Eq. (12). Similarly, statistics on predictions made by the two models will not be easily comparable because in the one case error is additive and in the logarithmic case error is exponential and multiplicative.

The first step in estimating the coefficients for Eq. (20) is to convert to logarithms the data for cost (in thousands of dollars) and for weight shown in Table 1. The next step is to calculate the least-squares estimates of b and $\log a$. The results of these calculations are

$$\begin{aligned} \log y &= -1.0425 + 1.0241(\log x), \\ r^2 &= .560, \\ SE_{\log} &= .2763, \\ t_b &= 3.19, \\ df &= 8. \end{aligned} \quad (23)$$

The antilogarithms of both sides of Eq. (23) give

$$y = (.09060x)^{1.0241}, \quad (24)$$

where y = cost in thousands of dollars,
 x = weight in pounds.

Based on the coefficient of determination (r^2) and the calculated t -value (t_b), these results appear to be slightly better than those obtained with the linear case. However, care must be exercised in comparing the logarithmic with the linear form and in evaluating the logarithmic form itself. There are significant differences between the two forms. A hint of these differences is given by the fact that the standard error for the logarithmic case ($SE_{\log}$) is the standard error of the logarithms of the original numbers and not the standard error of the numbers themselves. For this reason, the standard error for the logarithmic case ($SE_{\log} = .2763$) is about 20 times smaller than the standard error for the arithmetic or linear case ($SE = 5.808$). Thus, the relative sizes of these standard errors do not give a direct indication of the equation that has the smaller standard error in terms of the original numbers, which are the numbers of interest in cost analysis.

*It is possible to estimate relationships such as those represented by Eq. (19) directly. For example, see C. A. Graver and H. F. Boren, Jr., Multivariate Logarithmic and Exponential Regression Models, The Rand Corporation, RM-4879-PR, July 1967. Although direct nonlinear estimating techniques have some desirable properties, they are much less widely used in cost analysis than the linear methods.

A review of the manner in which least-squares estimators are calculated will help to clarify this difference and to explain how these results can be compared. The technique is to find $\hat{a}$ and $\hat{b}$ such that

$$\sum_{i=1}^n (y_i - \hat{y}_i)^2 \quad (25)$$

is minimized. In the logarithms of the numbers, however, this is equivalent to finding the minimum value of

$$\sum_{i=1}^n \left[\log \left(\frac{y_i}{\hat{y}_i} \right) \right]^2, \quad (26)$$

since $(\log y_i - \log \hat{y}_i) = \log y_i / \hat{y}_i$. Thus, by transforming the variables to logarithms, the sum of the squares of the logarithms of the ratios rather than the sum of the squares of the differences between the observed and actual values of y are minimized.

The full impact of this change can be best illustrated by an examination of the way in which the difference affects the calculation of prediction intervals. To obtain prediction intervals for cost estimates when a logarithmic equation is used, the intervals are first calculated directly with the logarithmic data and they are then converted to natural numbers. Thus, the end points of the interval in logarithmic form are

$$\log \hat{y} - A_{\epsilon/2} \quad \text{and} \quad \log \hat{y} + A_{\epsilon/2}, \quad (27)$$

where

$$A_{\epsilon/2} = (SE_{\log}) t_{\epsilon/2} \sqrt{\frac{n+1}{n} + \frac{(\log x - \log \bar{x})^2}{E(\log x_1 - \log \bar{x})^2}}.$$

For the case where $x = \bar{x}$, these end points become

$$\log \hat{y} - (.2764) t_{\epsilon/2} (1.049) \quad \text{and} \quad \log \hat{y} + (.2763) t_{\epsilon/2} (1.049). \quad (28)$$

When antilogarithms of these numbers are used, the following prediction interval end points for the ϵ level of significance are obtained:

$$(\hat{y}) 10^{-.2898 t_{\epsilon/2}} \quad \text{and} \quad (\hat{y}) 10^{.2898 t_{\epsilon/2}}, \quad (29)$$

which are equivalent to

$$\frac{\hat{y}}{10^{.2898 t_{\epsilon/2}}} \quad \text{and} \quad (\hat{y}) 10^{.2898 t_{\epsilon/2}}. \quad (30)$$

These results show that the prediction interval band for the original numbers, based on a logarithmic regression analysis, is both nonsymmetrical and proportional to the predicted values. Further, the standard error for the logarithmic case ($SE_{\log}$) is more comparable with the coefficient of variation (CV) for the arithmetic case than it is with the standard error (SE) for the arithmetic case, because the standard error for the logarithmic case (like the coefficient of variation for the linear case) is a proportion.

The band for the standard error is delineated by the following locus of points for the various values of y :

$$\frac{y}{10^{.2763}} \quad \text{and} \quad (y) 10^{.2763} \quad (31)$$

Thus, the upper and lower bounds of the standard error band at the sample mean value of y (9.06) based on the logarithmic regression analysis is given by the following numbers:

$$\frac{9.06}{10^{.2763}} \quad \text{and} \quad (9.06) 10^{.2763},$$

which equals 4.80 and 17.12, respectively. When these numbers are expressed as differences around the mean, 8.06 is obtained for the upper half of the interval and 4.26 for the lower half.

Figure 10 shows a graph of the values of the standard error for other values of y and the band for the 90-percent prediction intervals plotted above and below the regression line. These bands about the regression line illustrate both the nonsymmetry and the proportionality of these measures for the logarithmic case: nonsymmetry in that the distance between the regression line and the upper bounds is greater than that for the lower bounds; and proportionality in that the bounds become wider as y becomes larger. Because the standard error for the logarithmic case is a constant percentage of y , the absolute value of the bounds change as the value of y changes.

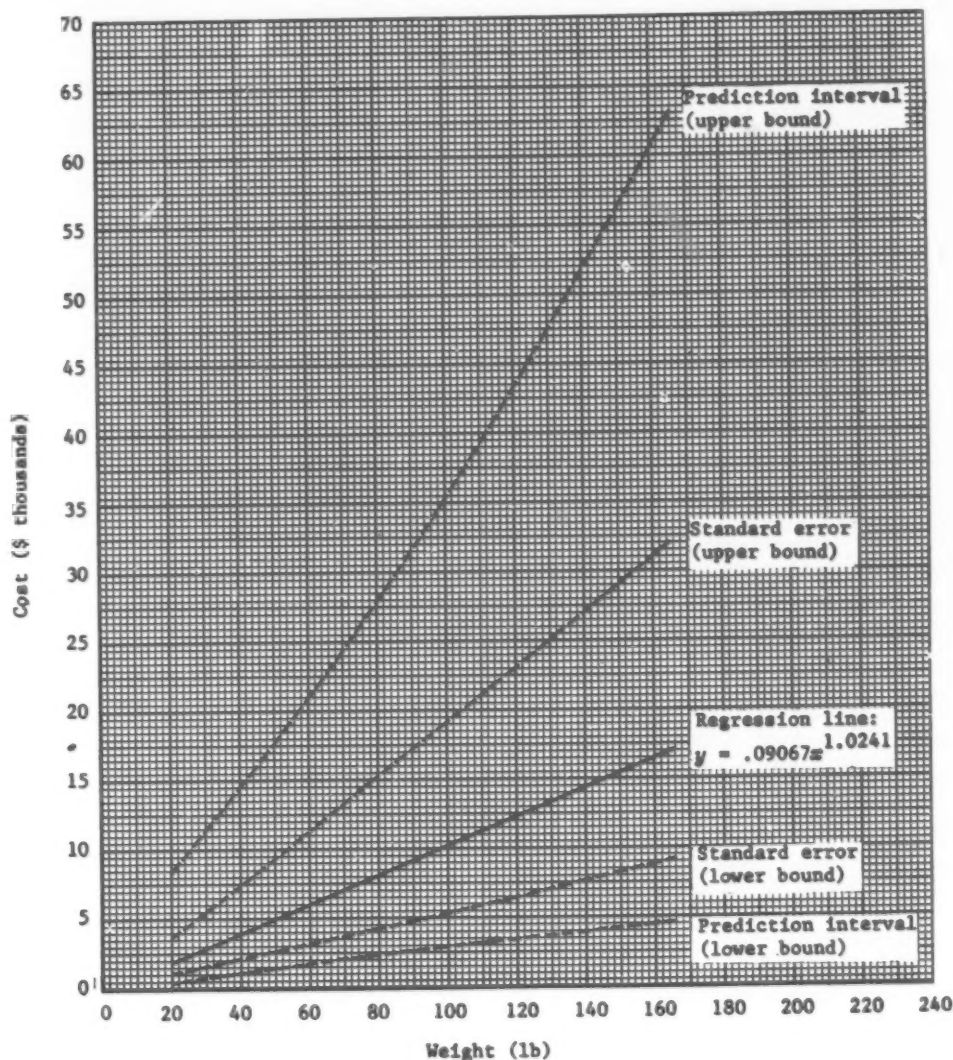


Figure 10. Logarithmic Equation With Standard Error and 90-Percent Prediction Intervals

In Figure 11, an interval of plus and minus \$5,808 (the amount of the standard error in the arithmetic case) and the standard error as shown in Figure 10 have been plotted about the regression line that was obtained with the logarithmic transformation. Figure 11 illustrates the way in which the standard error based on the logarithmic regression analysis compares with the results that were obtained from the arithmetic equation. The interval of plus \$5,808 intersects the upper bound of the standard error at the point where $x = 65$ lb. The interval of minus \$5,808 intersects the lower bound at $x = 121$ lb. Thus, for all estimated values of y greater than \$12,300, the interval based on the value of the standard error of the arithmetic case is less than the lower bound of the standard error calculated from the logarithmic analysis. Similarly, for all estimated values of y greater than \$6,500, this interval is less than the upper bound (logarithmic case).

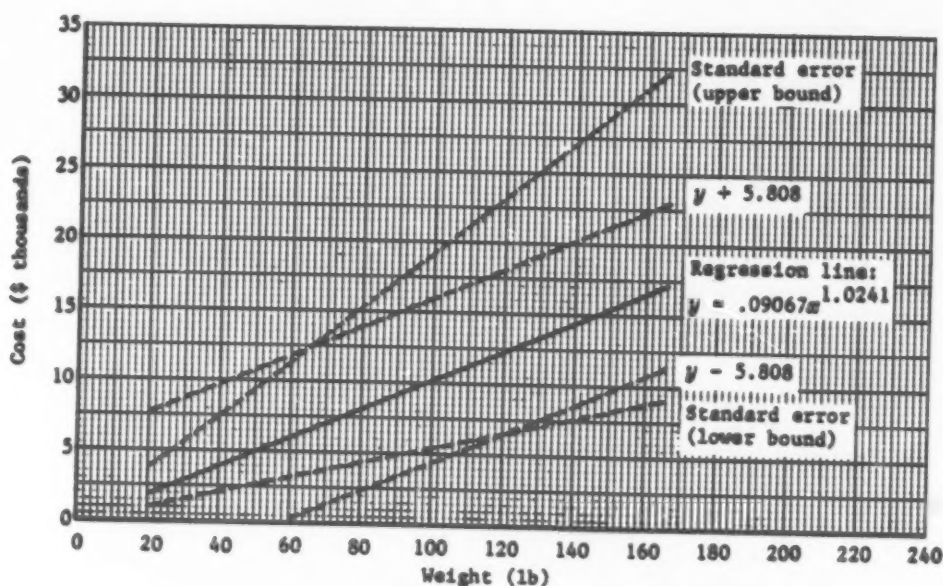


Figure 11. Comparison of Standard Error for Logarithmic Equation With Interval Based on Standard Error From Arithmetic Equation

On the basis of these considerations, it can be seen that the comparisons of the logarithmic results and the arithmetic results are difficult and can often be misleading. Higher coefficients of determination for the logarithmic case do not necessarily imply that this case is better from the viewpoint of explaining cost variance in the original numbers. Comparisons of the standard errors for these two cases is usually not possible without a full examination of the differences as illustrated in Figures 10 and 11.

However, on the positive side, some relationships are, in fact, nonlinear, and logarithmic transformations provide a practical means for estimating nonlinear exponential relationships with linear estimating techniques. Although there are techniques for estimating exponential forms directly with nonlinear estimating techniques,* there are also some difficulties in comparing and evaluating these results. Because the direct estimating techniques for exponential forms are nonlinear, they do not possess all the properties that are required to permit the direct application of standard regression analysis.

Another useful application of logarithmic regression analysis arises in cases in which empirical evidence or experience indicates that the assumption of proportional variance, rather than constant variance, seems more appropriate. Frequently, a simple scatter diagram such as that shown in Figure 6 is sufficient to indicate whether proportional or constant variance is more appropriate. Alternately, the sample could be divided into two or more groups, and tests could be performed on the means of the absolute values of the residuals in the linear case of each group. If the higher values of the dependent variables have residuals that are greater in value, the assumption of proportional variance would be indicated. The use of a logarithmic transformation is a convenient way to transform the data to conform to the requirement of proportional variance. If constant variance is assumed in the logarithms of the numbers, standard regression analysis can be performed in the logarithms. However, the assumption of constant variance in the logarithms implies proportional variance in the original numbers.

*See, for example, Graver and Boren.

3. MULTIPLE REGRESSION ANALYSIS.

To this point, simple (one explanatory variable) regression analysis has been used to examine both the linear and the nonlinear relationship between cost and weight. With the array of data shown in Table 1 and the logarithmic transformations of these data, multiple (more than one explanatory variable) regression analysis will now be examined. This section covers the multiple linear and the multiple nonlinear (exponential) case; for the latter, logarithmic transformations will be used. Because the sample documented in Table 1 contains only ten observations, the examination will be limited to various combinations of two rather than three explanatory variables. If additional observations were included in the sample, three explanatory variables might be considered under certain circumstances; however, this number of variables used with ten observations would detract from the credibility of the results. In any event, there is no great loss in limiting the number of variables to two; the essential differences between simple and multiple regression can be illustrated with the two-explanatory variable case.

In the linear case, the estimating equation is of general form

$$y = a + bx + cz. \quad (32)$$

The results for each of the possible combinations of two from the set of three explanatory variables are as follows:

$$C = -3.752 + .104(W) + .018(F), \quad (33a)$$

(2.61) (1.72)

$$C = 2.930 + .074(W) + .0047(P), \quad (33b)$$

(1.12) (0.19)

$$C = -0.526 + .045(P) + .027(F), \quad (33c)$$

(2.82) (2.38)

where C = cost in thousands of dollars,
W = weight in pounds,
F = frequency in megahertz,
P = power in watts.

The number in parentheses below each of the estimated coefficients is the value of the t-ratios for each of these coefficients. However, since an additional variable has been added, the degrees of freedom for these equations is 7 rather than 8, as it was for the simple case. Thus, the appropriate value of t in testing for null hypothesis for each of the coefficients is 1.895 rather than 1.860.

To understand the use of t-ratios in multiple regression equations, the meaning of the multiple regression coefficients must be understood. In each case, the multiple regression coefficients shows the net effect of an explanatory variable. For example, Eq. (33a) can be interpreted as follows: For a given frequency, a 1-lb increase in weight will cause a \$104 increase in cost. Alternatively, for a given weight, a 1-MHz change will cause the expected cost to change by \$18. As the independence between the explanatory variables decreases, the validity of this interpretation and the use of multiple variables diminish. For example, if weight and frequency are related in such a way that a change in weight cannot be assumed with frequency constant, the use of both variables in a single multiple regression equation can produce spurious results (e.g., the wrong sign on a coefficient, such as a negative sign for the weight coefficient).

Fortunately, there are quantitative indicators that are useful in evaluating empirically the significance of such interdependencies on regression results. Allowance for interdependence is built into the formula for calculating the standard error of each coefficient in multiple regression equations. Thus, the t-ratios in a multiple regression not only serve to indicate the significance (or nonsignificance) of each of the explanatory variables but also indicate when there is an unacceptably strong relationship between these variables.

From Eq. (33b), it can be seen that the inclusion of power with weight causes weight to become nonsignificant at the 10-percent level of significance. Weight was, however, significant at this level in the simple regression case. The coefficient of determination between weight and power is .533, which indicates that over 50 percent of the total variance in weight could be explained by a regression of weight on power. Thus, the adverse effect on the significance of weight that results from the inclusion of power can be attributed to the existence of interdependence between these two variables.

As the degree of interdependence increases, regression results become less stable and more indeterminate. As a consequence, the t-ratio should not be the sole test for assessing the amount of interdependence present.* Further, it is not possible to give a precise cutoff point at which explanatory variables must always be considered too interdependent. A coefficient of .9 or more will almost certainly cause problems; one of .3 or less usually will not. The array of correlations and coefficients of determination among the explanatory variables should always be examined in the early stages of analysis, and, to the extent possible, the use of interdependent explanatory variables should be avoided.

It is also possible for variables to be nonsignificant in multiple regression equations, even when there is no high level of interdependence. For example, in Eq. (33a) the coefficient of frequency is nonsignificant at the 10-percent level although the coefficient of determination between frequency and weight is only .091. Frequency in conjunction with weight is simply not a useful explanatory variable. Regardless of the reason, nonsignificant variables should not ordinarily be retained in regression equations used for cost estimating. Only one of the three multiple regression equations shown above produces an acceptable result: This is Eq. (33c), in which frequency and power are used as explanatory variables, and both are statistically significant.

The question arises, For cost-estimating purposes, is the multiple regression with power and frequency preferable to the simple regression with weight as the explanatory variable? To find an answer, the other measures by which the regression equations are judged must be compared: the standard error of estimate, the coefficient of variation, and the coefficient of determination. These are shown in Table 4 for each of the multiple regressions for comparison with the results obtained from the simple regression. The primary concern in this comparison is between the multiple regression with frequency and power and the simple regression with weight, since the power and frequency equation is the only one in which both the explanatory variables are significant. For completeness, however, the results for all three of the linear multiple regressions are shown and will be discussed.

Table 4

COMPARISON OF MULTIPLE-LINEAR WITH SIMPLE-LINEAR REGRESSION RESULTS

Statistical Measure	Explanatory Variables			
	Weight	Weight and Frequency	Weight and Power	Frequency and Power
Standard error	5.808	5.204	6.192	4.999
Coefficient of variation	0.641	0.574	0.683	0.552
Coefficient of determination	0.325	0.526	0.329	0.563
Degrees of freedom	8	7	7	7

Equation (33a), in which weight and frequency are used, appears to give slightly better results in a comparison with the other measures. However, the coefficient of the frequency variable is not significant at the 10-percent level. As a consequence, the improvement is not a statistically significant one. The generalized test to determine whether the incremental improvement associated with the addition of a variable is significant uses an F-statistic.** The test performed with this statistic is similar to the t-test. In this case, the null hypothesis is that the increment is not significant. The statistic used to test this null hypothesis is

$$F = \frac{\text{Increment of explained variance} \div \text{degrees of freedom}}{\text{Remaining unexplained variance} \div \text{degrees of freedom}}$$

This can be rewritten as

$$F = \frac{(R^2 - r^2)/1}{(1 - R^2)/7} \quad (34)$$

where R^2 = the coefficient of determination of the equation that includes weight and frequency,
 r^2 = the coefficient of determination of the equation with weight alone.

*In the limiting case of the two explanatory variable regressions in which one variable is an exact linear function of another, the regression results become completely indeterminate since the attempt is then to fit a plane in two dimensions, and there are an infinite number of planes intersecting each line in the two-dimensional space. An excellent discussion of this point is found in John Johnson, Econometric Methods, McGraw-Hill Book Company, Inc., New York, 1963, pp. 201-207.

**See F. E. Croxton, D. J. Cowden, and S. Klein, Applied General Statistics, 3d ed., Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1960, p. 627.

Equation (34) shows only 1 degree of freedom involved in the numerator, which is the incremental degree of freedom lost by adding another coefficient. The degrees of freedom in the denominator equal the number of observations in the sample less the number of coefficients estimated.

Substituting the appropriate coefficients of determination in the formula for the F-statistic, we obtain

$$F = \frac{(.526 - .325)}{(1 - .526/7)} = \frac{(.201)(7)}{.474} = 2.97. \quad (35)$$

This value falls short of the critical value of F, which equals 3.95 at the 10-percent level of significance. Thus, the null hypothesis is accepted, and we conclude that the net increment in explained variance associated with the addition of frequency to the equation containing weight is insufficient to establish that the improvement is not due to chance.

In Eq. (33b), in which weight and power are used as explanatory variables, it can be seen that the loss of the degree of freedom associated with adding another variable more than offsets the slight increase in the proportion of explained variance (R^2). As a result, the standard error in this case is greater than it is for the case where weight is used alone (6.192 versus 5.808). Thus, not only are the variables not significant, but the equation would also produce slightly less satisfactory (larger) prediction intervals than simple regression, although the coefficient of determination is slightly larger.

Equation (33c), in which power and frequency are used as explanatory variables, compares favorably with the simple regression in which weight is used, and thus far appears to be the best estimating equation derived. However, to complete the analysis, the nonlinear equations should be examined. These equations, expressed in the logarithms of the original numbers, have the general form

$$\log y = \log a + b(\log x) + c(\log z). \quad (36)$$

The results for each of the possible different combinations of two that can be developed from the set of three explanatory variables are as follows:

$$\log C = -1.8576 + 1.1385(\log W) + .2743(\log F), \quad (37a)$$

(3.78) (1.62)

$$\log C = -0.6582 + .7145(\log W) + .1542(\log P), \quad (37b)$$

(1.46) (.842)

$$\log C = -1.1933 + .5756(\log P) + .6085(\log F), \quad (37c)$$

(8.44) (5.91)

where C = cost in thousands of dollars,
W = weight in pounds,
F = frequency in megahertz,
P = power in watts.

The other measures required to complete the comparisons between the various equations are shown in Table 5.

The major patterns in the nonlinear multiple regression equations compared with the nonlinear simple case are similar to those for the linear equations. The use of both frequency and weight produces slightly better results, but the coefficient of the frequency variable is not statistically significant at the 10-percent level. The use of power with weight again produces a larger standard error than the simple case although the coefficient of determination is slightly larger. In all respects, the best nonlinear equation is the equation that uses power and frequency as explanatory variables. In addition, this nonlinear equation has a significantly larger coefficient of determination than the best linear equation. The best linear equation also uses power and frequency and has a coefficient of determination of .563. The nonlinear form has a coefficient of determination of .913.

The remaining question is whether the nonlinear results are sufficiently superior to the linear results to conclude that the nonlinear equation should be used in preference to the linear one. The standard error for each in the original numbers at the mean and as a percentage of the mean should be compared. If the results show that the standard error for the nonlinear case is smaller, this evidence, and the fact that the coefficient of determination for the nonlinear case is much larger, can be used as a basis to judge in favor of the nonlinear form.

Table 5

COMPARISON OF MULTIPLE-NONLINEAR WITH SIMPLE-NONLINEAR REGRESSION RESULTS

Statistical Measure	Explanatory Variables			
	Log Weight	Log Weight and Log Frequency	Log Weight and Log Power	Log Frequency and Log Power
Standard error	0.2763	0.2518	0.2814	0.1312
Coefficient of determination	0.560	0.680	0.600	0.913
Degrees of freedom	8	7	7	7

When the formulas shown in Eq. (31) are used, the end points that delineate the standard error at the mean for the nonlinear equation are

$$\frac{9.060}{10^{0.1312}} \text{ and } (9.060)10^{0.1312}.$$

When the end points are simplified, the following values are obtained:

$$6.698 \text{ and } 12.255.$$

These results, expressed as differences from the mean, give values of 2.362 below and 3.195 above the mean. Thus, the lower band of the standard error for the nonlinear case is 26 percent of the mean and the upper bound is 35 percent. This compares favorably with the coefficient of variation from the linear case, which is about 55 percent. Thus, given the inherent limitations of the small sample size of 10, the use of the nonlinear form improves the results significantly. The preferred equation is

$$\log C = -1.1933 + .5756(\log P) + .6085(\log F), \quad (38)$$

or

$$C = (.0641)P^{.5756}F^{.6085},$$

where C = cost in thousands of dollars,
P = power in watts,
F = frequency in megahertz,
log = logarithm base 10.

This equation is also acceptable on logical grounds since the estimated relationships between cost and power and cost and frequency are positive.

4. DOCUMENTATION.

Once an estimating relationship has been developed, a report that documents the data, assumptions, and analytical results is indispensable. The following guidelines for preparing the report are suggested:

- Describe the scope and coverage of the study and of the equations that have been developed.
- Assuming that the study has provided for a survey of work already performed in the area of interest (a desirable part of any cost-research study), prepare a summary of the survey results.
- Describe the major input data used in the study. The raw and adjusted data, which includes data for both the dependent and explanatory (independent) variables, should be documented to the extent that is feasible. Include data not only for those cost categories and characteristics used in the final estimating equations, but also for those characteristics that were considered but were eliminated in the process of analysis. Describe and explain fully any adjustments to the raw data; indicate limitations and accuracy. Because one of the outputs of a cost-research study is the data base itself, documentation should be such that the data base will be useful in future studies.
- Identify sources and dates of the data.
- Define each dependent and explanatory variable considered in the study. (Unambiguous definitions of weapon system characteristics and cost elements are usually more involved than appears at first glance.)
- Provide the major dependent- versus single-explanatory-variable scatter diagrams used in the study. The diagrams should be labeled to identify each data point.

- g. Document the final equations as well as the other major equation forms examined in the study; include such statistics as the standard error of estimate, coefficient of determination, coefficient of variation, and prediction intervals to the extent that they are derived for each equation. Other criteria that are considered appropriate for indicating the goodness of fit and prediction capabilities of the equations should be described.
- h. For the major final equations, prepare a table such as Table 6 to show the observed values of the dependent variables, the estimated values, the deviations, and the percent deviation from the observed values. In addition, prepare a scatter diagram, such as that illustrated in Figure 12, on which the observed values versus the estimated values are plotted. The points on the diagram should be labeled to identify each item. (Figure 12 shows that the apparent problem of stratification illustrated in Figure 4 has been eliminated by including frequency as an explanatory variable.)

Table 6

ACTUAL AND ESTIMATED COSTS OF AIRBORNE COMMUNICATION EQUIPMENT

Actual Cost (\$)	Estimated Cost (\$)	Deviation (Actual less estimate) (\$)	Percent Deviation
22,200	13,768	+8,432	+38
17,300	16,970	+1,330	+8
11,800	17,388	-5,588	-47
9,600	9,238	+362	+4
8,800	9,238	-438	-5
7,600	6,435	1,165	+15
6,800	6,885	-85	-1
3,200	4,581	-1,381	-43
1,700	2,062	-362	-21
1,600	1,261	+339	+21

Average of absolute value of percent deviations = 20

- i. Describe the alternate equations that were considered and why they were rejected. The report should convey a sense of the improvement that results from a high degree of selectivity in choosing the final forms. The alternative equations could show
- (1) The use of different explanatory variables;
 - (2) Different forms of the equations, e.g., linear, multiplicative (linear in the logarithms), or other nonlinear forms;
 - (3) The use of different forms of the dependent variables, e.g., cost per pound or cost per item;
 - (4) The use of stratified dependent variables grouped into subcategories that are determined by such factors as ship or missile type, weight, frequency, or speed regime.
- j. Describe any special methodology in an appendix if only of special interest (e.g., a sophisticated mathematical approach).
- k. Describe the cost-estimating methods fully and clearly. It should be possible to reconstruct the results of the study from the data base as it is given in the report. The major assumptions, statistical and otherwise, used in the derivation of the equations should be explicitly stated.
- l. Provide an example to illustrate the procedure for using the final cost-estimating relationship.
- m. Describe the limitations of the final equations as specifically as possible. State the range of characteristics over which the estimating procedure applies and any other restrictions on the population covered by the equations.

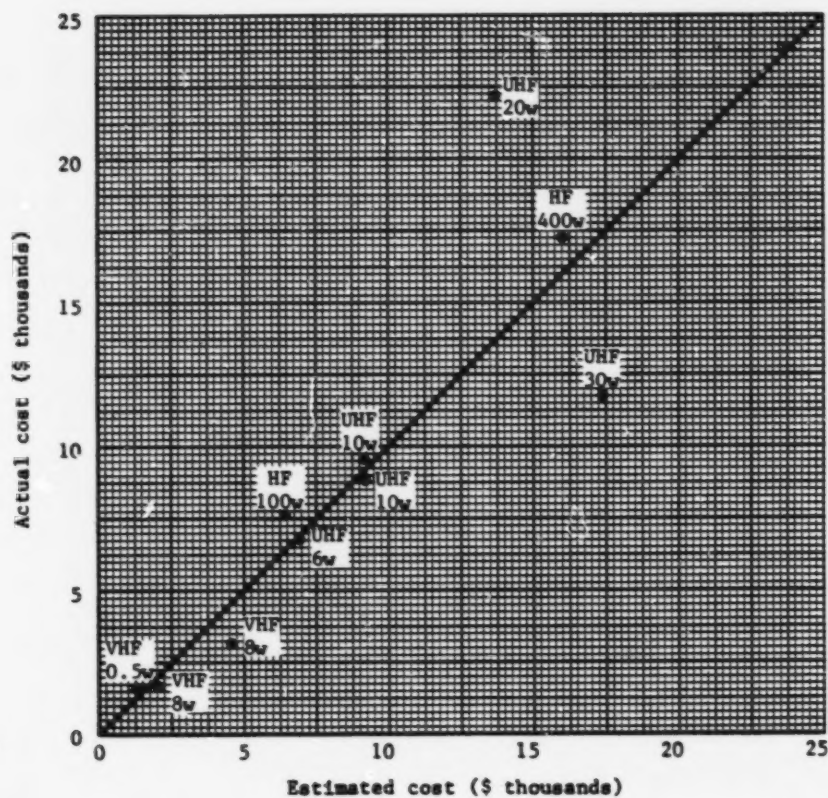


Figure 12. Actual Cost Versus Estimated Cost

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CHAPTER 14

USE OF COST ESTIMATING RELATIONSHIPS

The widespread use of estimating relationships in the form of simple cost factors, equations, curves, nomograms, and rules of thumb attest to their value and to the variety of situations in which they can be helpful. But an estimating relationship can only be derived from information on past occurrences, and the past is not always a reliable guide to the future. As all horseplayers know, the favorite runs out of the money often enough to prove that an estimate based on past performance is very likely to be wrong. Admittedly, there may be other factors at work in a horse race, but the problem remains the same as that encountered in any attempt to predict the course of future events, i.e., how much confidence can be put in the prediction? This question dominates all other considerations in any discussion of the use of estimating relationships.

These remarks are not intended to depreciate the value of estimating relationships. They are an important tool in an estimator's kit and, in many cases, the only tool. Thus, it is essential that their limitations be understood to preclude their improper use. The limitations of estimating relationships stem from two sources: first, the uncertainty inherent in any application of statistics and second, the uncertainty that an estimating relationship is applicable to a particular article. The first pertains primarily to articles well within the bounds of the sample on which the relationship is based; even here, uncertainty may be found. The second source refers to those cases in which the article has characteristics somewhat different from those of the sample. Although extrapolation beyond the sample is universally deplored by statisticians, it is universally practiced by cost analysts in dealing with advanced hardware because, in most instances, it is precisely those systems outside the range of the sample that are of interest. The question is whether the equation is relevant to the case under investigation, although good statistical practice would question the validity of such an approach.

1. CHARACTERISTICS OF THE ESTIMATING RELATIONSHIP.

The degree of emphasis placed on statistical treatment of data can cause two fundamental points to be overlooked: first, that an estimating relationship must be reasonable and second, that it must have predictive value.

Reasonableness can be tested in various ways--by inspection, by simple plots, and by complicated techniques that involve an examination of each variable over a range of possible values. Inspection will often suffice to indicate that an estimating relationship is not structurally sound. For example, the following equation is the result of an exercise at the Air Force Institute of Technology in which students were asked to develop cost-estimating relationships for small missiles.

$$C = 8347.5 + 150.6W - 1149.1R,$$

(1)

where C = cost of airframe + guidance and control,
W = weight in pounds,
R = range in miles.

This equation fits the data very well, but it states that as range increases, the cost decreases; such an assumption appears to be in error. If cost is a function of range, the relationship should be direct rather than inverse. To investigate further, choose two hypothetical but reasonable values for W and R within the range of the sample data: 38.5 - 157 lb for W; 5.0 - 14.8 mi for R. Table 1 shows that Missile B, although heavier and with greater range than Missile A, is estimated as the cheaper of the two, which is contrary to experience. A reexamination of the sample data and the equation is in order.

Table 1

SAMPLE COST COMPARISON OF TWO MISSILES

Hypothetical Missile	Airframe Weight + Guidance and Control (lb)	Range (mi)	Estimated Airframe Cost + Guidance and Control (\$)
A	50	5	10,132
B	75	10	8,152

When an estimating relationship is developed to make a particular estimate, it may have little predictive value outside a narrow range. As an example, consider the following equation for estimating the cost of solid-propellant motors for small missiles:

$$\text{Cost} = 1195.6 + .000003I^2,$$

(2)

where I = total impulse.

The equation fits the sample data very well:

Missile Motor	Observed Cost (\$)	Estimated Cost (\$)
A	2600	2660
B	1700	1693
C	1250	1265
D	1750	1781

If it were appropriate to use statistical measures for a sample of 4, Eq. (2) explains over 99 percent of the total variance. But, note that the constant 1195.6 accounts for 94 percent of the cost of Motor C and that the cost of all motors smaller than Motor C will be about \$1200. Because of the I^2 term, the influence of total impulse is likely to be too pronounced for motors larger than those in the sample.

A common method of examining the implications of an estimating relationship for values outside the range of the sample is to plot a scaling curve as shown in Figure 1. Scaling curves may be plotted on either arithmetic or logarithmic graph paper as Figure 1 illustrates; cost analysts usually prefer the log-linear representation. The theory on which a scaling curve is based is as follows: As an item increases in weight (or another dimension), the incremental cost of each additional pound (or square foot, watt, horsepower) will decrease or increase in a predictable way. Thus, in Figure 1 the cost per pound of an electrical power subsystem in a manned spacecraft decreases from about \$4200 to \$1400 as the total weight increases from 100 to 1000 lb. The slope of the curve is fairly steep; if the curve were extended to the right, it might be expected to flatten. Eventually, the curve might become completely flat at the point at which no more economies of scale can be realized, but it is unlikely that the slope would ever become positive.

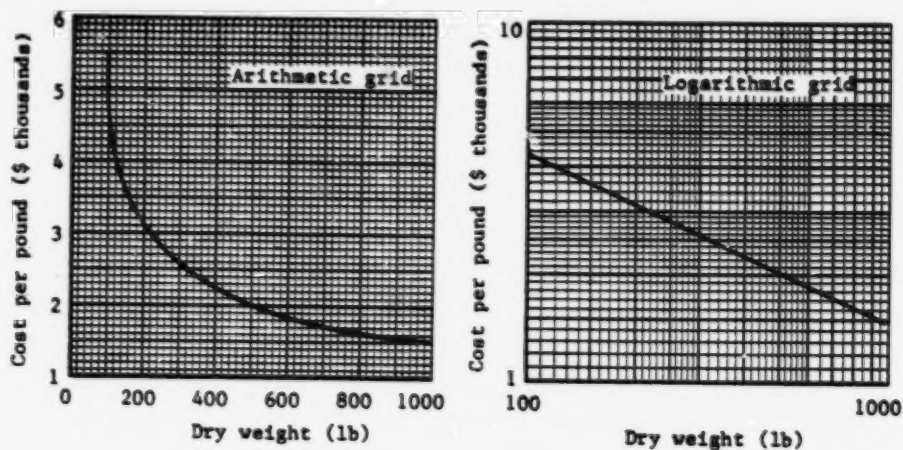


Figure 1. Scaling Curve: Cost Per Pound Versus Dry Weight

Now examine Figure 2 in which total impulse is plotted against cost per pound-second based on values obtained from an estimating relationship. Two differences are immediately seen. First, the lefthand portion of the curve is unusually steep. Second, the slope becomes positive when total impulse exceeds about 22,000 lb-sec. In some instances, fabrication problems increase with the size of the object being fabricated and a positive slope may result. No such problems are encountered in the manufacture of small, solid-propellant rocket motors, however, and continued economies of scale are to be expected.

Figure 2 illustrates another point: A more useful estimating relationship could have been obtained by drawing a trend line rather than by fitting a curve to the four data points. With a small sample, it is often possible to write an equation that fits the data perfectly, but the equation is useless outside the range of the sample. Statistical manipulation of a sample this size rarely produces satisfactory results.

A final example of the kind of error that undue reliance on statistical measures of fit may bring about is based on an estimating equation for aircraft airframes. Initially, the equation for estimating

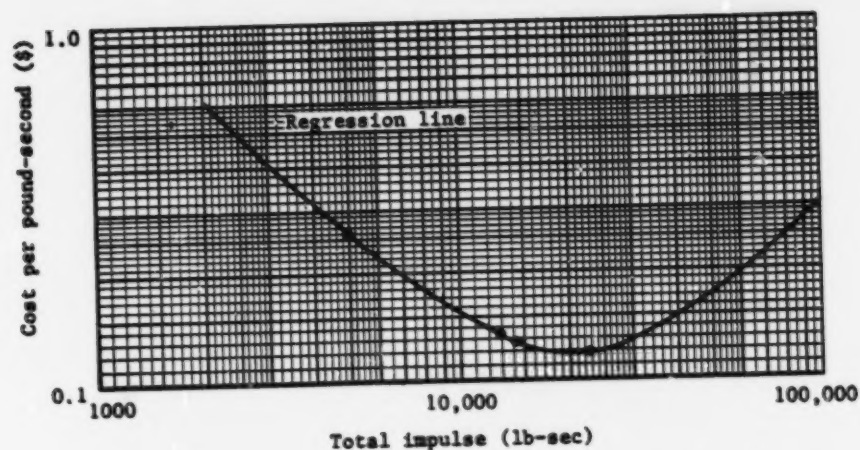


Figure 2. Cost Per Pound-Second Versus Total Impulse

airframe production labor hours was based on a sample of 44 aircraft. It then seemed that a grouping of the aircraft by type should give better correlation and, in fact, when the bombers, fighters, trainers, and cargo aircraft were considered separately, the average deviation between estimates and actual values was markedly reduced. For example, in the case of trainer aircraft, the average deviation was reduced from 20 to 6 percent, and a more useful estimating relationship was obtained. In the case of fighters, however, although average deviation was reduced from 15 to 11 percent, the estimating equation exhibited the flaw shown in Eq. (3):

$$\text{Manufacturing hours} = 4.28 (\text{weight})^{1.08} (\text{speed})^4. \quad (3)$$

The exponent of weight is greater than 1.0, which means that when speed is held constant and weight increased, the man-hours per pound of airframe weight will increase. This can be seen in Figure 3. The dashed lines show scaling curves derived from the total sample of 44 aircraft. These portray the normal relationship--as weight increases, hours per pound decrease. The regression equation gives the opposite results because the general trend in fighter aircraft has been for increased speed to be accompanied by increased weight, which causes an emphasis on the weight variable. It cannot be assumed, however, that all new fighters will conform to this trend; the equation, if used at all, would have to be used with great care.

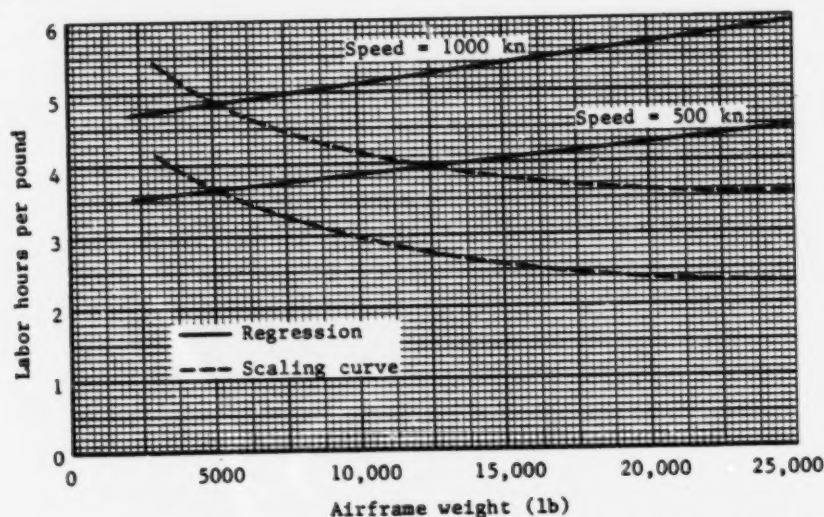


Figure 3. Comparison of Regression Lines with Scaling Curves

The advice is frequently given that an estimating relationship should not be used mechanically. This implies (1) that the function must be thoroughly understood and (2) that the hardware involved must be understood as well. To illustrate the first point, examine an estimating relationship for direct manufacturing hours derived from a sample of Navy and Air Force airframes:

$$H_{100} = 1.45W^{.74}S^{.43}, \quad (4)$$

where H_{100} = manufacturing labor hours required to produce the 100th airframe,

W = gross takeoff weight in pounds,

S = maximum speed in knots.

The multiple correlation coefficient is 0.98 and the coefficient of variation is .016 in logarithmic terms. Despite these satisfactory measures of fit, a comparison of the actual manufacturing hours for each airframe in the sample with those estimated by the equation provides a better understanding of how the relationship relates to the real world. In such a comparison, as shown by Table 2, 33 percent of the estimates differ from the actuals by more than 20 percent, a 7 percent differ by more than 30 percent. These figures imply that an analyst with only the estimating relationship on which to rely may or may not obtain a good estimate. However, if the less acceptable results can be explained in some way, the analyst is then in a much better position to understand the strengths and weaknesses of the equation.

Since this estimating relationship is based on gross takeoff weight and maximum speed, an initial hypothesis to explain the variations might be that the estimates decrease in quality at one end of the weight or speed range or in certain combinations of weight and speed. In this case, however, as shown in Figure 4, the poorer estimates are scattered throughout the sample, which indicates no consistent bias because of the explanatory variables.

Table 2

COMPARISON OF ACTUAL AND ESTIMATED MANUFACTURING HOURS

Difference Between Actual Hours and Estimated Hours (%)	Number of Airframes	Percentage of Sample
10 or less	15	56
11-20	3	11
21-30	7	26
31-40	2	7

A second hypothesis might be that the manufacturing history of the airframes in the sample explains the discrepancies and, in general, this hypothesis is valid. Of the nine airframes in the sample for which estimates differed from actuals by 20 percent or more, several were considered problem airframes, i.e., airframes for which the manufacturer encountered an abnormal number of problems in meeting weight and performance specifications. Interestingly enough, these were not aircraft in which a major state-of-the-art advance was being attempted. Another cause for discrepancy was the interspersing of different models of the same aircraft in a single lot: For example, reconnaissance versions of a bomber were interspersed among bomber airframes. Situations of this kind increase direct labor requirements. The two airframes for which the estimates were the poorest and for which almost 40 percent less labor than the equation predicted was required, were vastly different ones--a large transport and a supersonic fighter. Production of one of these airframes benefited from the manufacturer's concurrent experience with a commercial airplane of similar configuration. The other case cannot be explained. The amount of labor involved in producing the airplane was unusually low.

Although it is not possible to resolve all uncertainties with the information available, an estimator can feel reasonably confident that the estimating relationship does not contain a systematic bias, that it should be applicable to normal production programs, and that it provides reasonable estimates throughout the breadth of the sample.

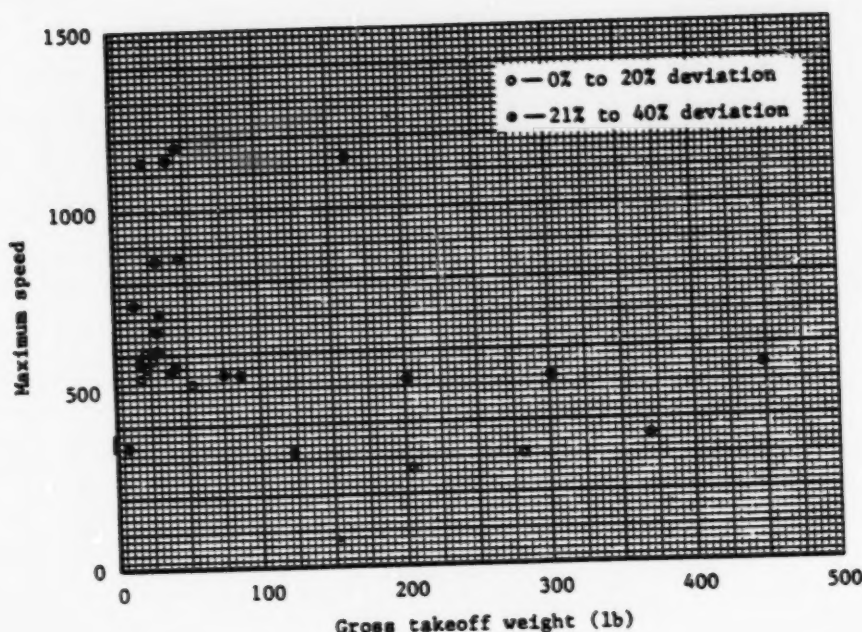


Figure 4. Plot of Sample Data

2. HARDWARE CONSIDERATIONS.

The sample included aircraft having gross takeoff weights of 6100 lb to 450,000 lb and maximum speeds of 300 kn to 1200 kn. Suppose that a proposed new aircraft has a gross weight of 600,000 lb and a maximum speed of 1700 kn. Should Eq. (4) be used as the estimating equation in this case? The same question could arise for an aircraft with weight and speed that are in the sample range, but which is to be fabricated by a new process or out of a new material. Again, the estimator must decide whether the equation is relevant or how it can be modified to be useful. An estimating relationship can be used properly only by a person familiar with the type of equipment whose cost is to be estimated. To say that an analyst who estimates the cost of a destroyer should be familiar with the characteristics of destroyers is a truism; however, an estimator is sometimes far removed from the actual hardware. Further, he may be expected to provide costs for air-to-air missiles one week and for a new antiballistic missile system the next. The tendency in such a situation may be to use the equation that appears most appropriate without taking the required measures to determine whether the equation is applicable.

To illustrate the problem, assume that a new supersonic bomber is proposed having a gross weight of 450,000 lb and a maximum speed of 1700 kn. Equation (4) may be inappropriate because the speed is far beyond the range of the sample. On the other hand, no equation exists for aircraft in that speed range, and an estimate is required. This situation may be regarded as the normal one, and there is no choice but to use what is available. In this example, Eq. (4) gives 542,000 direct labor manufacturing hours.

The next step is to compare the result with other similar systems to see if the estimate appears reasonable. In this instance manufacturing hours versus gross weight are plotted for several other large aircraft as shown in Figure 5. The supersonic bomber estimate SSB_1 is substantially above the trend as it should be, because a 1700-kn airframe will be more difficult to build than a subsonic airframe of the same size. If other information is lacking, an estimator might accept the figure of 542,000 hr. In this case, however, all the airframes in the sample were fabricated almost entirely of aluminum; an airframe built to withstand the heat generated by sustained flight in the atmosphere at a speed of about Mach 3 will require a metal such as stainless steel or titanium. The question that occurs is whether the speed variable in the equation fully accounts for this change in technology.

One way to answer this question is to plot a second scatter diagram, with speed as the independent variable. Figure 6 shows labor hours per pound of airframe weight plotted against speed with a calculated line of best fit drawn through the scatter. If an airframe weight of 125,000 lb out of a gross weight of 450,000 lb is assumed, the estimate of 542,000 hr is equal to 4.3 hr-lb of airframe, which not only is below the calculated trend line, but is also below any reasonable trend line that can be drawn through the sample. (This point is shown as SSB_1 in Figure 6.)

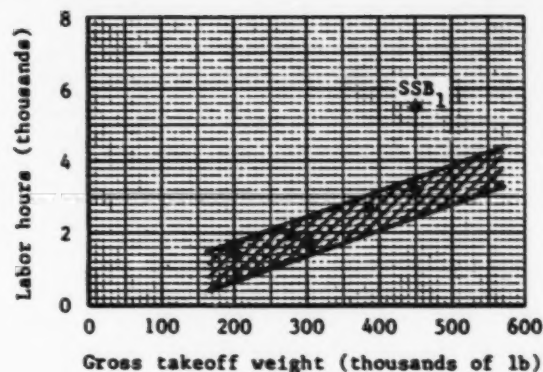


Figure 5. Trend Line for Large Aircraft

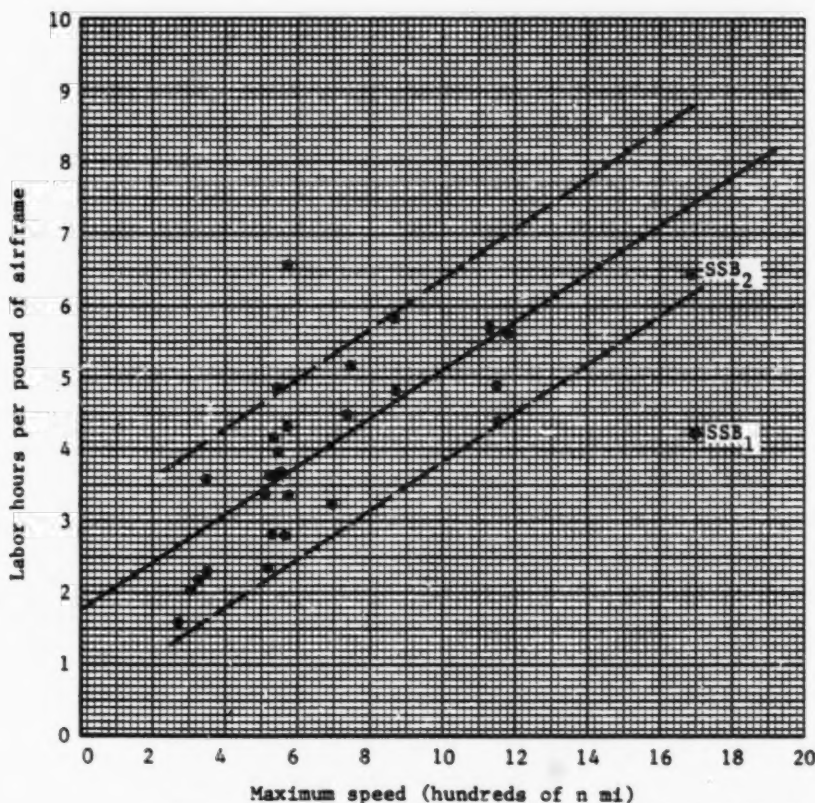


Figure 6. Labor Hours Per Pound Versus Maximum Speed

Three possible estimates can now be considered: 542,000 hr based on speed and weight; about 300,000 hr based on weight alone as shown by Figure 5; and about 925,000 hr based on speed alone as shown by the regression line in Figure 6 ($7.4 \text{ hr-lb} \times 125,000 \text{ lb} = 925,000 \text{ hr}$). More information is needed to narrow the range.

Although data are less than abundant, several experimental and prototype aircraft have been fabricated using stainless steel and titanium. On the basis of prototype experience, one manufacturer maintains that a titanium airframe requires twice the number of hours that an aluminum airframe requires; however, manufacturing hours for an aluminum airframe can vary considerably. A second approach is more precise. An examination of actual data for different airframes with speeds of Mach 3 and above shows that these airframes require about 1.5 times as many hours as the estimating relationship of Eq. (4) indicates,

which implies 813,000 hr or 6.5 hr-lb for the supersonic bomber. (This point is shown as SSB₂ in Figure 6.) On the basis of current knowledge, the estimate appears to be reasonable. Further measures could be taken in the form of another independent estimate that uses a different estimating relationship. An estimator does not have this option for most kinds of hardware, because estimating relationships are not plentiful. However, in the case of airframes, a number of equations have been developed over the years; it is good practice to use one to confirm an estimate made with another.

3. JUDGMENT IN COST ESTIMATING.

The need for judgment is often mentioned in connection with the use of estimating relationships. Although this need may be self-evident, one of the problems in the past has been too much reliance on judgment and too little on estimating relationships. The problem of introducing personal bias with judgment has been studied in other contexts, but the conclusions are relevant to this discussion. In brief, a person's occupation or position seems to influence his forecasts. Thus, a consistent tendency toward low estimates appears among those persons whose interests are served by low estimates, e.g., proponents of a new weapon or support system whether in industry or in Government. Similarly, there are people in industry and in Government whose interests are served by caution. As a consequence, their estimates are likely to run higher than would be the case were they free from all external pressures. (In fairness to this latter group, however, overestimates are rare enough to suggest that caution is not a quality to be despised).

The primary use of judgment should be to decide first, whether an estimating relationship can be used for an advanced system, and second, if so, what adjustments will be necessary to take into account the effect of a technology that is not present in the sample. Judgment is also required to decide whether the results obtained from an estimating relationship are reasonable. This does not mean reasonable according to a preconception of what the cost ought to be, but reasonable in a comparison with the past cost of similar hardware. A typical test for reasonableness is to study a scattergram such as Figure 7 of costs of analogous equipment at some standard production quantity. The estimate of the article may be outside the trend lines of the scattergram and still be correct, but an initial presumption exists that a discrepancy has been discovered and that this discrepancy must be investigated. An analyst who emerges from his deliberations with an estimate implying that new, higher performance equipment can be procured for less than the cost of existing hardware knows that his task is not finished. If, after research, he is convinced that the estimate is correct, he should then be prepared to explain the new development that is responsible for the decrease in cost. He should not raise the cost arbitrarily by a percentage to make the figure appear more acceptable or because he feels that the estimate is too low. (Such adjustments are the province of management and are generally occasioned by reasons somewhat removed from those discussed here.) Judgments must be based on well-defined evidence. The only injunction to be observed is that any change in an estimate be fully documented to ensure that the estimate can be thoroughly understood, and to provide any information that may be needed to reexamine the equations in the light of the new data.

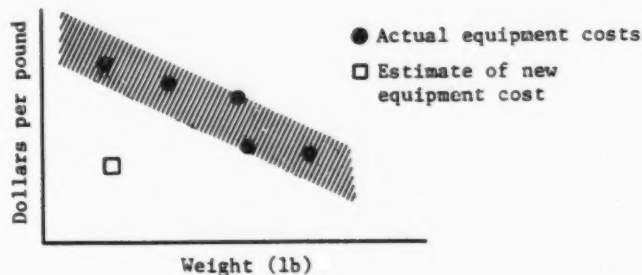


Figure 7. Cost Comparison of Analogous Equipment

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CHAPTER 15

THE LEARNING CURVE

For many years the aerospace industry has made use of what variously have been called "learning," "progress," "improvement," or "experience" curves to predict reductions in cost as the number of items produced increases. The learning process is a phenomenon that prevails in many industries; its existence has been verified by empirical data and controlled tests. Although there are several hypotheses on the exact manner in which the learning or cost reduction can occur, the basis of learning-curve theory is that each time the total quantity of items produced doubles, the cost per item is reduced to a constant percentage of its previous cost. Alternative forms of the theory refer to the incremental (unit) cost of producing an item at a given quantity or to the average cost of producing all items up to a given quantity. For example, if the cost of producing the 200th unit of an item is 80 percent of the cost of producing the 100th item, and if the cost of the 400th unit is 80 percent of the cost of the 200th, and so forth, the production process is said to follow an 80-percent unit learning curve. If the average cost of producing all 200 units is 80 percent of the average cost of producing the first 100 units, the process follows an 80-percent cumulative average learning curve.*

Either formulation of the theory results in a power function that is linear on logarithmic grids. Figure 1 shows a unit curve for which the reduction in cost is 20 percent with each doubling of cumulative output, the upper figure showing the curve on arithmetic grids and the lower on logarithmic grids. The arithmetic plot illustrates that the percentage reduction in cost in each unit is very pronounced for the early units. On an 80-percent curve, for example, cost decreases to 28 percent of the original value over the first 50 units. Over the next 50 units, it declines only 5 more percentage points, i.e., down to 23 percent of unit 1 cost. The factors that account for the decline in unit cost as cumulative output increases are numerous and not completely understood. Those most commonly mentioned are:

1. Job familiarization by workmen, which results from the repetition of manufacturing operations.
2. General improvement in tool coordination, shop organization, and engineering liaison.
3. Development of more efficiently produced subassemblies.
4. Development of more efficient parts-supply systems.
5. Development of more efficient tools.
6. Substitution of cast or forged components for machined components.
7. Improvement in overall management.

The above list of relevant factors is not complete, and it tends to understate the importance of the item sometimes considered the most important--labor learning. Labor cost, however, cannot decline through experience gained by workmen unless management also becomes more efficient. In other words, it is necessary for management to organize and coordinate more efficiently the work of all manufacturing departments so that parts and assemblies will flow smoothly through the plant.

Labor cost is not the only element of manufacturing that declines as cumulative output increases. A learning curve exists for unit materials cost. The materials category frequently includes much purchased equipment, which in turn includes a substantial number of engineering, tooling, and labor hours. Unit hours decline as production quantities increase, and the contractor who buys in successive lots is generally able to negotiate a lower price for each lot. Decreases in raw material costs are generally attributed to two factors as cumulative output increases: The workmen learn to work the raw materials more efficiently, cutting down spoilage and reducing the rejection rate, and management learns to order materials from suppliers in shapes and sizes that reduce the amount of scrap that must be shaved and cut from the pieces of sheet or bar to fabricate the item of equipment. Substitution of forgings for machined parts also reduces the amount of scrap material.

A second factor that is probably responsible to a lesser extent for the decline in materials cost is the pricing policy of the raw material suppliers. These suppliers generally reduce the price per pound for the various kinds of raw materials if an order is sufficiently large. Although the learning curve pertains to

*The quantities mentioned in connection with the learning concept presuppose the inclusion of all items. As concerns the J-79 engine used on the F-4 airplane, one would expect engine costs for the first 100 F-4s to be more than that for the second 100 airplanes. Although this is true, what is important is that the J-79 has been used on several other types of aircraft, and these uses, including full spare engines, must be considered in learning-curve analysis.

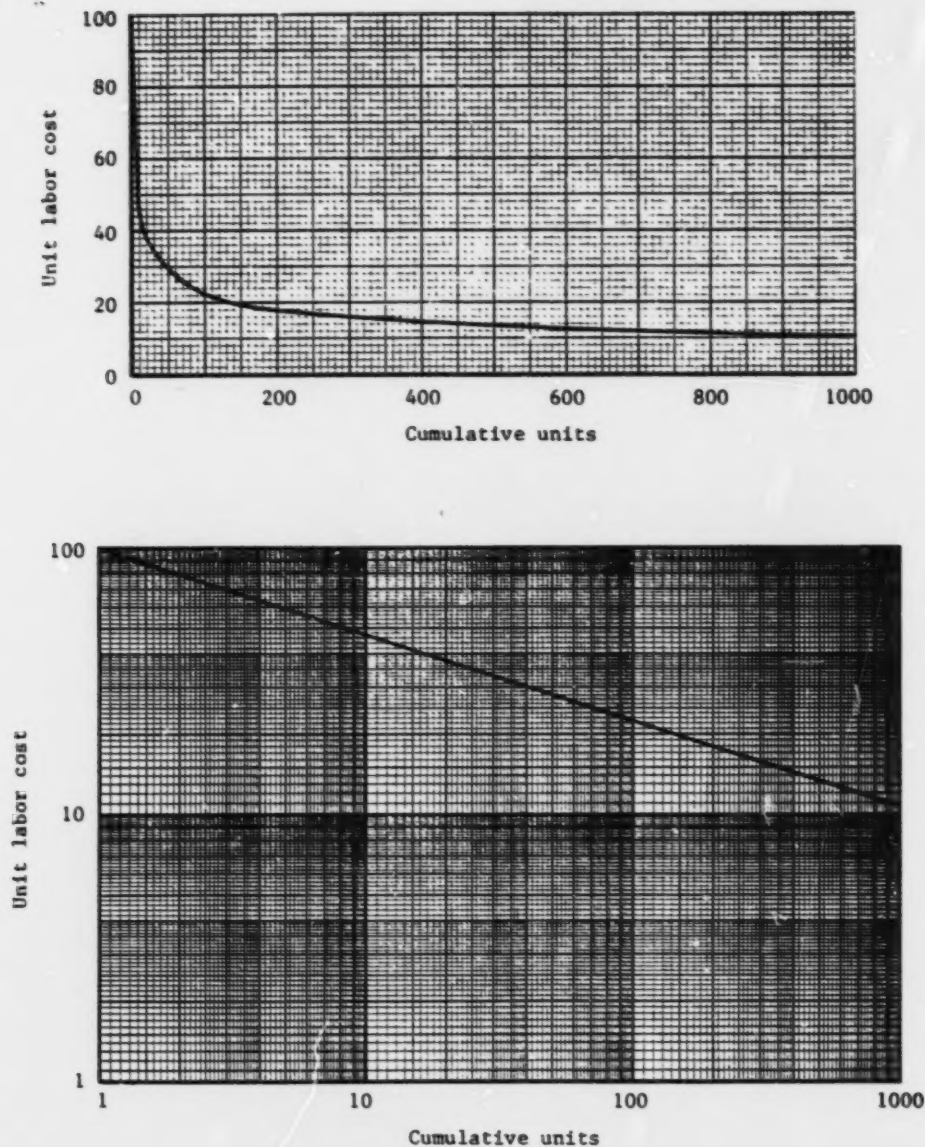


Figure 1. The 80-percent Learning Curve on Arithmetic and Logarithmic Grids

cost reductions as materials are applied to successive lots and not to reductions due to volume purchases, segregation of the two effects is imperfect. This may account for differences observed in learning-curve slopes.

A third major component of cost--overhead--also declines with cumulative output, but as a result of the method of allocating overhead and not because of a perceptible relationship between overhead rate and cumulative output. Direct labor hours per unit decline as cumulative output increases, and overhead is distributed to each unit on the basis of direct labor cost or hours. As a consequence, it is inappropriate to discuss a learning curve for this element of cost.

1. THE LOG-LINEAR HYPOTHESIS.

The relationship between cost and quantity may be represented by a power (log-linear) equation of the form

$$y = ax^b,$$

where x equals the cumulative production quantity. The relationship corresponds to a unit or a cumulative average learning curve according to whether y is the cost of the x th unit or the average cost of the first x units. The constant a is the cost of the first unit produced. The exponent b , which measures the slope of the learning curve, bears a simple relationship to the constant percentage to which cost is reduced as the quantity is doubled. If S represents the fraction to which cost decreases when quantity doubles, the equation becomes

$$S = \frac{y_{2x}}{y_x} = \frac{a(2x)^b}{ax^b} = 2^b \quad \text{or} \quad b = \frac{\log S}{\log 2}$$

This equation shows that for a value of S equal to 75 percent, the corresponding value of b is*

$$\frac{\log .75}{\log 2} \quad \text{or} \quad -.415.$$

- a. Log-Linear Unit Curve. If a production process follows a unit learning curve of the form $y_u = ax^b$, the cumulative cost T of producing the first n units is

$$T = a \sum_{x=1}^n x^b.$$

The cumulative average cost y_c of producing the first n units is then

$$y_c = \frac{T}{n} = \frac{a}{n} \sum_{x=1}^n x^b.$$

The relationship between the unit curve and the cumulative average curve is shown by Figure 2. The function y_c is not log-linear; however as x becomes larger, y_c approaches asymptotically the value

$$\frac{a}{b+1} x^b,$$

which differs from the expression for unit cost only by the constant factor $1/(b+1)$. Consequently, if unit cost has been estimated at a sufficiently large quantity, the cumulative average cost for the same quantity may be approximated by multiplying the unit measure by $1/(b+1)$.**

- b. Log-Linear Cumulative Average Curve.

When a production process follows a log-linear cumulative average curve rather than a unit curve, the basic functional form is still $y = ax^b$ but can be written $y_c = ax^b$, where y_c is the average cost of the first x units. The cumulative cost for producing x units is simply $y_c x$, or ax^{b+1} , and the unit cost is obtained from the function

$$a[x^{b+1} - (x-1)^{b+1}].$$

*In learning-curve literature, the term slope often refers to this percentage reduction; e.g., a 75-percent slope means a curve with a b value of $-.415$.

**Whether a quantity is sufficiently large for the asymptotic method to provide a good approximation depends on the slope of the learning curve. For a 90-percent curve, the asymptotic method produces an error of about 1 percent at quantity 100; for a 75-percent curve, the error at quantity 100 is almost 5 percent and does not decrease to 1 percent until a quantity of almost 2000 has been reached.

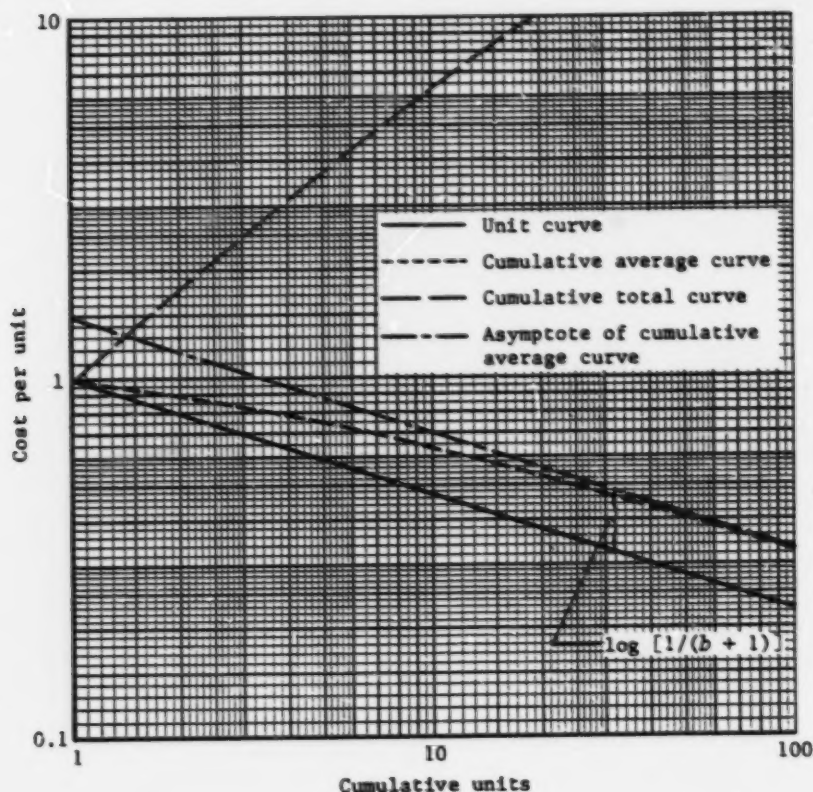


Figure 2. Log-Linear Unit Curve (80-percent slope)

The relationship between a log-linear cumulative average curve and the resulting unit curve is illustrated in Figure 3. The unit curve is not log-linear; however, as x becomes larger, y_u quickly approaches asymptotically the value

$$(b + 1)ax^b,$$

which differs from the cumulative average cost equation only by the constant factor $(b + 1)$.

These equations may appear cumbersome, but in practice much of the work involved in using learning curves has been simplified by the preparation of tables giving the relationship between cumulative total, cumulative average, and unit cost for a range of slopes and quantities. Table 1 gives values for these relationships for a 70-percent curve when a , the cost of the first unit produced, is equal to 1. To illustrate how such a table is used, assume a log-linear unit curve and a quantity n of 20 units. The total cost of 20 units is approximately 7.4, the cumulative average cost of 20 units is .37, and the cost of the 20th unit is .214, in terms of the cost of the first unit. The unit cost of .214 appears in the dual-headed column, y_u , y_c , since a log-linear unit curve is assumed. If a log-linear cumulative average cost curve is assumed, this column presents the cumulative average cost. One column serves to present both log-linear unit and log-linear cumulative average since the functional form of the equation $y = ax^b$, is the same in either case.

In practice, the unit cost is most frequently considered to be linear, but there are sufficient exceptions to suggest that the choice must be based on past experience. Once the choice is made, however, it is of the utmost importance to apply the technique consistently.

As is evident from Table 1, large errors could result if one type of curve was confused with the other.

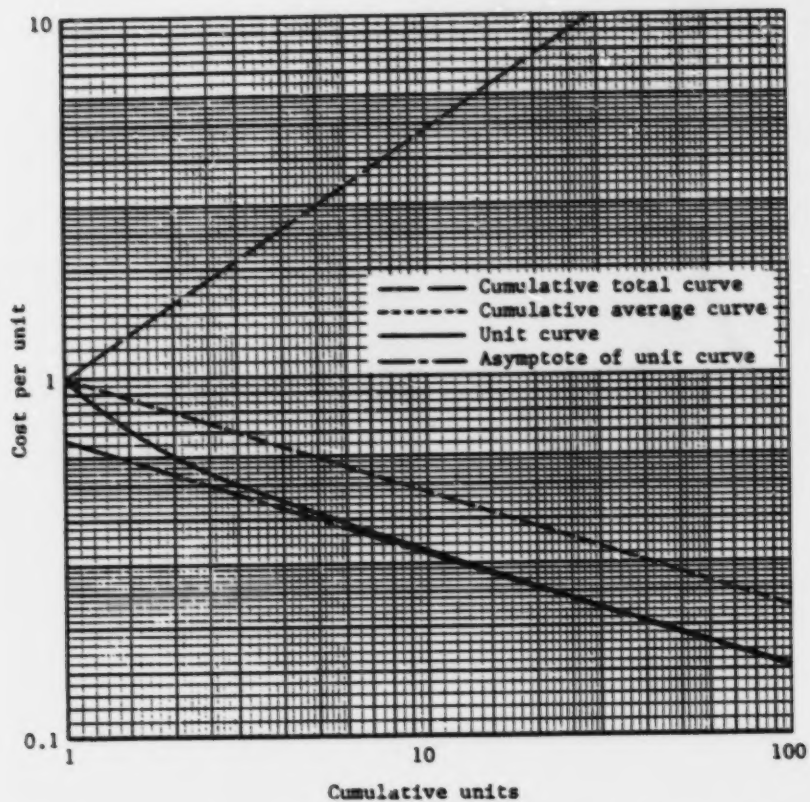


Figure 3. Log-Linear Cumulative Average Curve (80-percent slope)

Table 1

70-PERCENT CURVE DATA

n	Log-linear Unit		Log-linear Cumulative Average		
	Cumulative Total	Cumulative Average	Cumu- lative Average Unit	Unit	Cumulative Total
	T	y_c	y_u, y_c	y_u	y_c^n
1	1.000000	1.000000	1.000000	1.000000	1.000000
2	1.700000	0.850000	0.700000	0.400000	1.400000
3	2.268180	0.756060	0.568180	0.304541	1.704541
4	2.758180	0.689545	0.490000	0.255459	1.960000
5	3.195027	0.639005	0.436846	0.224232	2.184232
6	3.592753	0.598792	0.397726	0.202125	2.386357
7	3.960150	0.565736	0.367397	0.185419	2.571777
8	4.303150	0.537894	0.343000	0.172223	2.744000
9	4.625979	0.513998	0.322829	0.161460	2.905460
10	4.931771	0.493177	0.305792	0.152465	3.057925
11	5.222928	0.474812	0.291157	0.144802	3.202727
12	5.501336	0.458445	0.278408	0.138173	3.340900
13	5.768511	0.443732	0.267174	0.132365	3.473266
14	6.025688	0.430406	0.257178	0.127222	3.600487
15	6.273896	0.418260	0.248208	0.122626	3.723113
16	6.513996	0.407125	0.240100	0.118487	3.841600
17	6.746721	0.396866	0.232726	0.114734	3.956334
18	6.972702	0.387372	0.225980	0.111310	4.067644
19	7.192481	0.378552	0.219780	0.108171	4.175816
20	7.406536	0.370327	0.214055	0.105279	4.281095
21	7.615284	0.362633	0.208748	0.102604	4.383699
22	7.819094	0.355413	0.203810	0.100119	4.483818
23	8.018295	0.348622	0.199201	0.097804	4.581622
24	8.213180	0.342216	0.194886	0.095639	4.677261
25	8.404015	0.336161	0.190835	0.093609	4.770870
26	8.591037	0.330425	0.187022	0.091702	4.862572
27	8.774462	0.324980	0.183425	0.089904	4.952476
28	8.954487	0.319803	0.180024	0.088206	5.040682
29	9.131290	0.314872	0.176803	0.086600	5.127282
30	9.305035	0.310168	0.173745	0.085076	5.212359
31	9.475873	0.305673	0.170838	0.083629	5.295988
32	9.643943	0.301373	0.168070	0.822252	5.378240
33	9.809373	0.297254	0.165430	0.080940	5.459180
34	9.972281	0.293302	0.162908	0.079687	5.538867
35	10.132777	0.289508	0.160496	0.078490	5.61735

2. NONLINEAR HYPOTHESIS.

Throughout this chapter it will be assumed that the log-linear hypothesis applies, i.e., that the learning curve is linear when plotted on logarithmic grids. It must be mentioned, however, that this is not the only possible formulation of the learning curve. A number of studies have suggested that the curve is not log-linear. One of the best known of these is the Stanford Research Institute investigation of 20 World War II aircraft. They study proposed

$$y = \frac{a}{\sqrt{x+B}}$$

as a more reliable expression of the relationship between man-hour cost and cumulative output. The decision to find a substitute function was apparently prompted by a visual inspection of several series that seemed to indicate a concavity when viewed from below in the unit learning curve.* This concavity has been recognized independently in other studies.

However, in some cases both the labor and production cost curves develop convexities beyond certain values of cumulative output. In the theory of a linear unit curve, it is implicitly assumed that constituent curves (fabrication, subassembly, and major and final assembly) are parallel to the linear unit curve, implying that the rate of learning on all production jobs in all departments is the same. However, it is to be expected that the departmental learning curves could have different slopes from each other (e.g., fabrication, 80 percent; subassembly, 75 percent; and major and final assembly, 70 percent). The sum of these curves (the unit curve) would be convex when viewed from below and approach as a limit the flattest of the departmental curves.

Much literature is available describing the bases for, and hypotheses about, learning curves, and it is beyond the scope of this chapter to attempt to cover this background material in any detail.** For this discussion, it is stipulated that the learning curve is a useful and accepted estimating tool, particularly in the aerospace industry, that the log-linear curve is the one most commonly used, and that a knowledge of its mechanics is indispensable to persons making or using cost estimates.

3. PLOTTING A CURVE.

In the graphical display of learning curves, the problem is to represent the average cost for a lot or a complete contract, since typically, man-hours or costs are not recorded by unit. See, for example, the following table:

<u>Lot</u>	<u>Units</u>	<u>Manufacturing Hours per Lot</u>
1	1-10	5,830
2	11-20	4,370
3	21-50	10,550
4	51-100	14,750

*In this context, concavity means that when plotted on logarithmic grids the curve declines at an increasingly steep slope as it moves away from the y-axis. In the formulation

$$y = \frac{a}{\sqrt{x+B}}$$

the curve becomes essentially linear as x becomes large relative to B.

**There is one subject that is not discussed in the literature: the effect of production rate on unit cost. Economic theory generally holds that this relationship can be described by a U-shaped function: First, cost declines as production rate increases; next, it is insensitive to rate over some range; and eventually, it begins to rise again. In learning-curve applications, on the other hand, it is assumed implicitly that cost is not affected by rate of output (or that the rate is constant). Empirical evidence of the interaction between the volume and rate effects is scanty. For further discussion, see Lee E. Preston and E. C. Keachie, "Cost Functions and Progress Functions: An Integration," American Economic Review, Vol. 54, No. 2, Part I, March 1964, pp. 100-107.

To plot a cumulative average curve from these data, the cumulative average hours are computed at the final unit in each lot:

<u>Plot Point</u>	<u>Manufacturing Hours per Lot</u>	<u>Computation</u>	<u>Cumulative Average Hours</u>
10	5,830	$5,830 \div 10$	583
20	4,370	$10,200 \div 20$	510
50	10,550	$20,750 \div 50$	415
100	14,750	$35,500 \div 100$	355

The cumulative average at the 10th unit is 583 hours; this is the first plot point. Successive plot points are at the end of each lot, since these are the points where the cumulative average hour figures apply.

To plot the unit curve it is first necessary to compute the unit hours and then to establish plot points. The unit hours can be taken as an average for each lot:

<u>Lot</u>	<u>Computation</u>	<u>Unit Hours</u>
1	$5,830 \div 10$	583
2	$4,370 \div 10$	437
3	$10,550 \div 30$	352
4	$14,750 \div 50$	295

The lots can be represented by these unit hour values. The question is, where should the values be plotted? To plot at the lot arithmetic midpoint is to assume that the learning curve can be approximated by a linear curve on arithmetic grids, but as suggested by Figure 1 such a method of approximation only becomes reasonable for lots following a large number of previous units. Thus, when dealing with a log-linear function, the arithmetic midpoint plot produces the unequal distribution of the area under the curve, as shown in Figure 4.

The true midpoint is defined as that unit, x_m , which represents the entire lot and which must also reflect the average unit cost, y_m , of the lot. The total cost (or total hours) of the lot is equal to the product of y_m and the number of units in the lot, n . This product will approximate the area under the curve for n units (see Figure 5).*

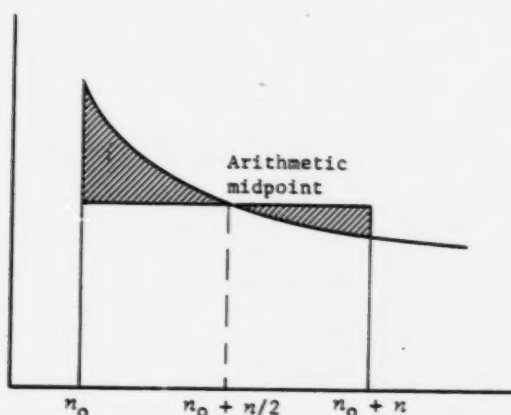


Figure 4. Learning Curve on Arithmetic Grids

*If n represents only integers, the limits of the area must be modified. (See H. Asher, Cost-quantity Relationships in the Airframe Industry, The Rand Corporation, R-291, July 1, 1956, pp. 34-38.)

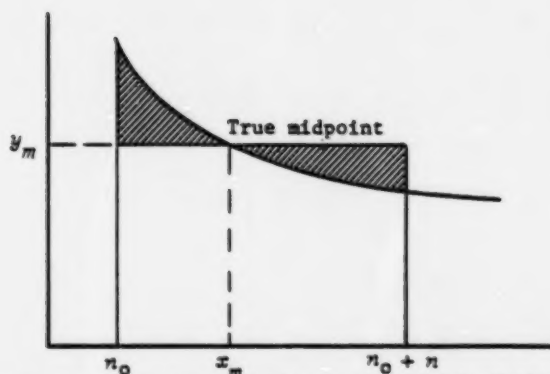


Figure 5. True Lot Midpoint on Arithmetic Grids

Note that if the area under the curve is equal to $y_m n$, the two crosshatched areas in the figure must be equal. In fact, the exact determination of a true lot plot point for plotting purposes depends on (1) the lot quantity; (2) the type of curve hypothesized, i.e., whether the unit curve or the cumulative average curve is log-linear; and (3) the true value of the slope. Therefore, these values must be known or assumed. The first, the lot quantity, will be known. The second, the nature of the curve, must be assumed. The third, the true value of the slope, is actually never known, and is usually approximated based on prior experience.

It is possible to ascertain the exact lot plot points for each type of curve over a range of slopes and quantities. However, because of the assumptions mentioned above that will usually have to be made regarding both the type of curve and its approximate slope, in most situations there is little need to strive for extreme accuracy. The following discussion provides methods of approximation that do not involve the complicated calculations required to derive the true lot plot point.

As illustrated in Figure 5, y is the average cost for the lot as well as the unit cost of the lot plot point x . Therefore, tables similar to Table 1 can be used to derive acceptably accurate plot points. To illustrate, assume a log-linear unit curve of 70 percent, a first lot of 10 units, and a first unit cost of 1. Then, the cumulative average cost y of the first 10 units is .493. This average cost lies between unit cost values y_u of .568 and .490, i.e., between units 3 and 4 on the unit curve. Arithmetic interpolation yields a value for x of slightly less than 4, which is the plot point for this particular lot when a 70-percent log-linear unit curve is assumed. An exact solution to the plot point equation would show the true plot point for a 70-percent curve to be 3.95. Similarly, if the first unit cost is 1 and if a 70-percent log-linear cumulative average curve is assumed, data from Table 1 yield a plot-point approximation of slightly less than 3 (the cumulative average cost for 10 units is .306, which lies between unit cost values of .400 and .304, i.e., between units 2 and 3 on the unit curve); the true plot point is 2.98. In this example, the plot points vary because of the assumption that one or the other of the curves is log-linear. This method of approximation produces accurate first-lot plot points for all but very small lot sizes. As a general rule, the steeper the slope and the smaller the lot size, the less accurate this approximation method becomes.

For the successive lots following a preceding quantity, the same procedure can be used for approximating plot points. To illustrate, again using Table 1, assume that a quantity of 10 units follows the first lot of 10 units. If a 70-percent log-linear unit curve and a unit cost of 1 are assumed, the total cost of the second lot may be obtained by subtracting 4.93 (the total cost of the first 10 units) from 7.4 (the total cost of 20 units), or a difference of 2.47. This represents an average cost of .247 for the 10 items in the lot. This value falls between units 15 and 16 on the unit curve, and simple interpolation gives a value of 15.1 for the plot point. If a log-linear cumulative average curve is assumed, the approximation value of the plot point is also 15.1. In other words, from Table 1, the difference between the cumulative total for 20 and 10 units, 4.28 and 3.06, respectively, is 1.22, or an average of .122 for the 10 units in the lot. This unit cost lies between .1226 and .1185 or units 15 and 16 on the unit curve.

Tables to permit computation of lot plot points for a range of slopes and lot quantities are available in the literature.* In addition, an easier-to-use, but less accurate, approximation method will be discussed that provides plot points for early lot quantities of less than 100.

*See, for example, H. E. Boren, Jr. and H. G. Campbell, Learning Curve Tables, Vols. 1-3, The Rand Corporation, RM-6191-PR, February 1970.

Figure 6 presents an approximation of the plot point for the first lot. It illustrates that substantial errors are possible when deriving first-lot plot points. The abacissa represents first-lot quantity and the ordinate the first-lot plot points associated with each quantity. For the upper dashed curve, a 95-percent log-linear unit curve is assumed; for the upper solid line, a 95-percent log-linear cumulative average curve is assumed. Approximation methods suitable for one type of curve cannot be used for another type unless extremely large quantities are dealt with, i.e., well beyond those shown in the figure. Figure 6 also shows the greater sensitivity to slope exhibited by the log-linear cumulative average curve for moderately small first lots.

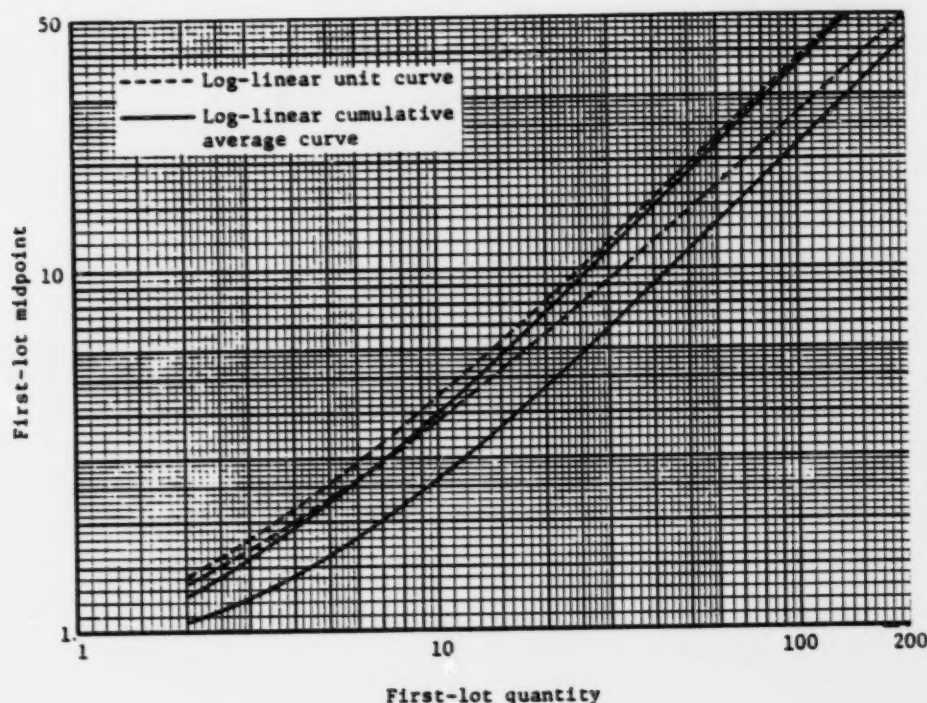


Figure 6. First-Lot Midpoints Versus First-Lot Quantities

In addition, it affords an opportunity to approximate quickly the range of error that can be introduced by inappropriate plotting of the cost of the first lot.

Figure 7 gives plot points for follow-on lots. These points represent an average of the range obtained from 65- to 95-percent curves and the range obtained from a log-linear unit or a log-linear cumulative average curve. The graph is used as follows:

- The first unit of the contract lot is found on the 45-deg line.
- The curve extending out from this unit is followed to the point on the horizontal axis that represents the last unit of the lot.
- The plot point is read off the vertical axis at that point. Thus, for a lot of 10 units following 10 previous units, the plot point would be slightly over 15.

In practice, plot points for only the first two or three lots, if these comprise more than about 25 units, need be taken from the graph. For succeeding lots, the arithmetic lot midpoint is usually adequate.

As a further illustration, Figure 8 shows two sets of curves. The lower set of curves was constructed from a series of small contract lots, 10, 29, and 31 units. The upper set of curves was based on two

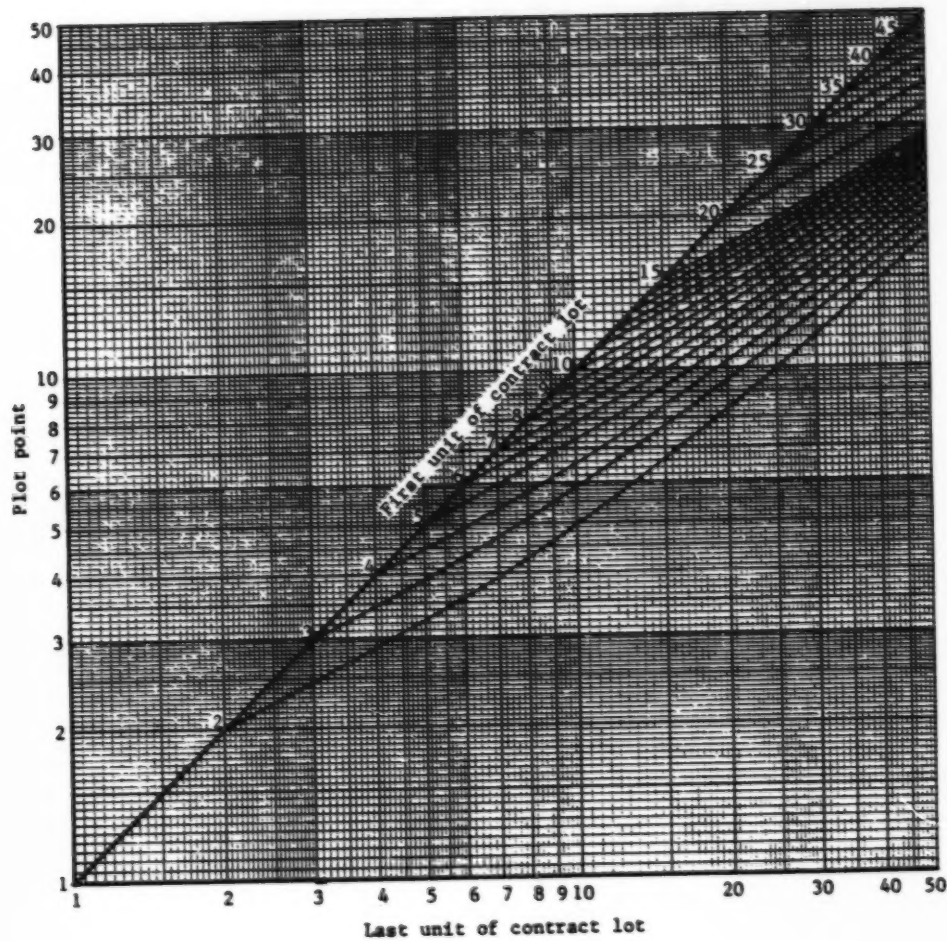


Figure 7. Plot Points for Average Costs

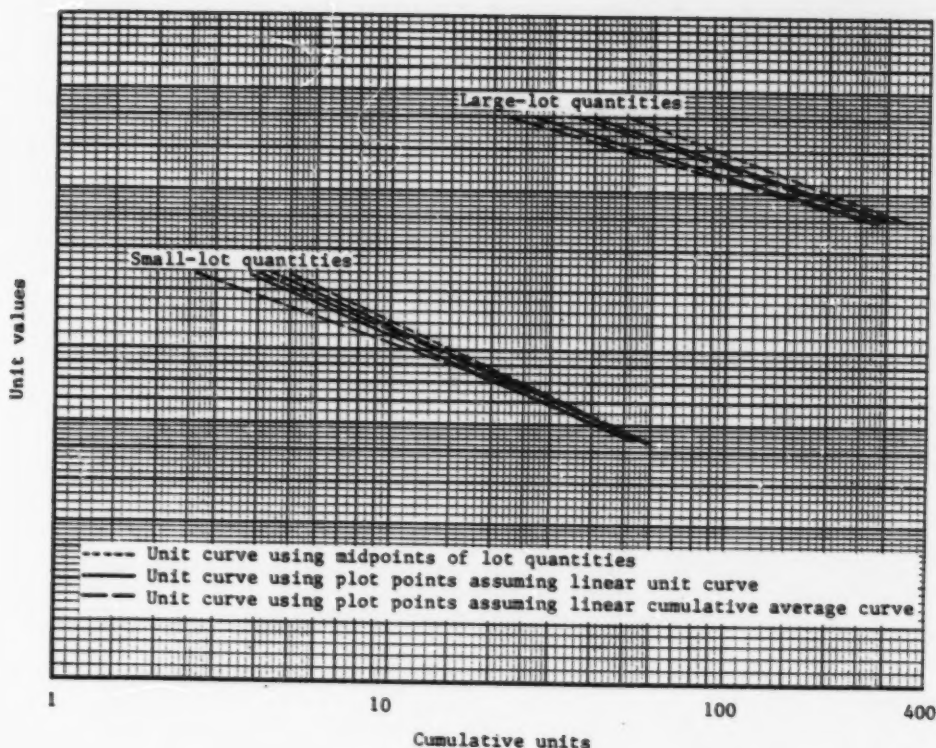


Figure 8. Unit Curves from Contract Lot Averages

large contract lots, 100 and 500 units. With lot average costs, the costs were plotted (1) at lot quantity arithmetic midpoints, (2) at plot point where a log-linear unit curve for 65- and 95-percent slopes was assumed, and (3) at plot points where a log-linear cumulative average curve for 65- and 95-percent slopes was assumed.

From Figure 8 it can be seen that the distance between the unit curve constructed with the arithmetic midpoint and the unit curve constructed with the true plot points depends on the size of the lot quantity. The larger the lot quantity, the greater the distance between the midpoint line and the other lines. In both sets the unit curves exhibit the widest variation for the first lot. However, for a series of small contract lots the range of plot points is of interest only for the first few lots. The midpoint of even the second-lot quantity may often provide a good approximation of the unit curve.

It is not the purpose of this discussion to recommend any particular technique. Rather, it is to underline that plotting representative unit costs for contract lots is of importance. The gross misplacement of early points could lead to improper conclusions about cost-quantity relationships.

4. VARIATIONS.

The examples used earlier tend to suggest that data points generally fall along a straight line, as one would expect from the log-linear hypothesis. The truth is that plots of the type illustrated in Figure 9 are not unusual and that fitting a curve to these points is more than a matter of understanding the least-squares method of curve fitting. The types of plots in Figure 9 are common enough to have been given names by the airframe industry. The "scallop" is generally caused by a model change or some other major interruption in the production process. Characteristic of a scallop is the abrupt rise in manufacturing hours, followed by a rapid decline, the basic slope of the curve remaining relatively unchanged. When a model change is sufficiently great, as in the case of the change to the F-106B from the F-106A, the result is not a scallop but a change to a new curve. In this case, a "level-off" or "follow-on" is characteristic of the initial portion of the new curve. This is attributed to learning from a previous model that carries over and flattens the curve during initial production. Such an

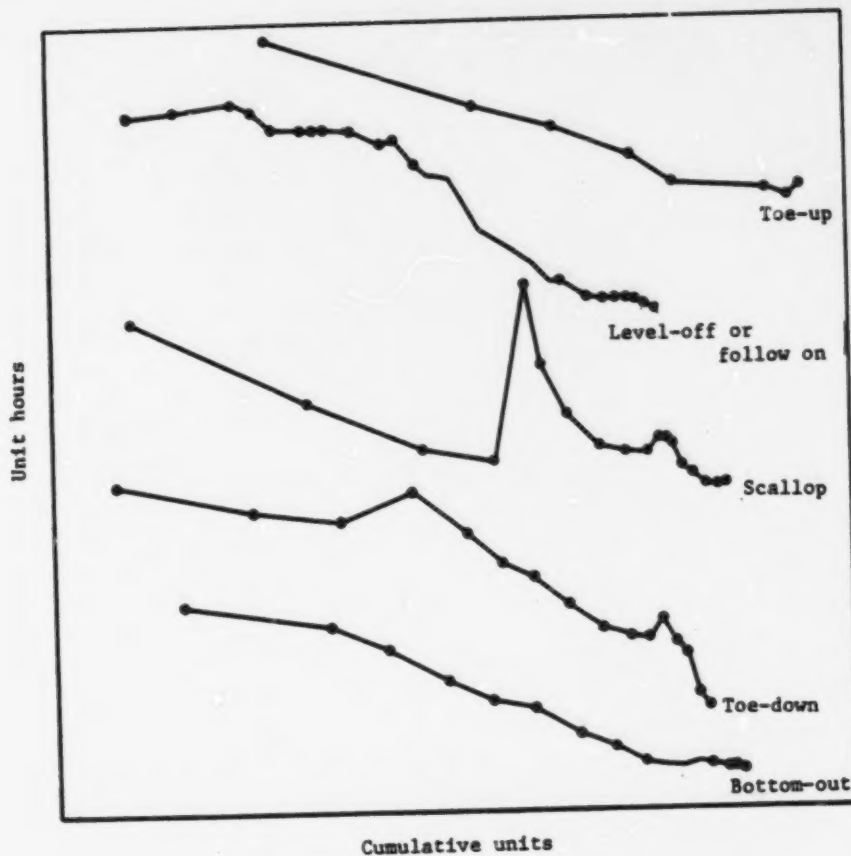


Figure 9. Illustrative Examples of Learning-Curve Slopes

effect can also occur when production is halted for a long period or when production is transferred to a new facility.

To "bottom-out" is the tendency for a learning curve to flatten at high production quantities. It seems reasonable that at some point no further learning should occur or that whatever slight learning does occur would be offset by the effect of other factors. In addition, it can be established empirically that bottoming-out has occurred in a number of cases. There are those who argue, however, that learning can continue indefinitely, or at least as long as the attempt is made to obtain man-hour reductions. The classic case relates to the assembly of candy boxes, in which operation the learning curve was found to have continued for the preceding 16 years when 16 million boxes were assembled by one person.* The problem for the estimator, of course, is that while bottoming-out may occur in any given case, it is difficult to predict where it will occur. One study found that for the sample of airframes examined it was fairly typical for flattening to begin at the 300th unit,** but in the past this has not been true for many airframes. The B-17 curve maintained a 70-percent slope out to the 6000th unit and then exhibited a toe-up.

* Glen E. Ghormley, "The Learning Curve," Western Industry (now Western Manufacturing), September 1952, pp. 31-34.

** Planning Research Corporation, Methods of Estimating Fixed-wing Airframe Costs, Volume I (Revised), PRC R-547A, Los Angeles, April 1967.

"Toe-ups" and "toe-downs" are the names given to the rather sharp rises or falls in hours that sometimes occur at the end of a production series. The upward trend has been explained as resulting from the transfer of experienced workers to other production lines, an increase in the amount of handwork as machines are disassembled, failure to replace or repair worn tooling at the normal rate, tool disassembly, or a production lag at the end of a program to forestall unemployment.* Toe-downs are thought to be caused by fewer engineering changes at the end of a production run and also by the ability of the manufacturer to salvage certain items fabricated in previous lots.

It is important to realize that such variations in production do occur, and not occasionally but frequently. In the analysis of man-hour or cost data, use of the unit curve reveals these variations, and for this reason the unit curve is generally preferred. The cumulative average curve tends to smooth out aberrations to such an extent that even major changes can be obscured, as shown in Figure 10. The data points are taken from a fighter aircraft production program that had more than its share of problems. The solid line shows how a cumulative average curve dampens the effect of these problems. The choice between working with the unit or the cumulative average curve depends on the problem. The unit curve better describes the data and is therefore preferred. In addition, its use can aid the cost analyst in determining whether the basic curve is best represented by a log-linear cumulative average or unit function, what slope is most appropriate, and what follow-on projections can be made. The log-linear cumulative average curve is widely preferred in predictive models because of its computational simplicity; i.e., the cost of n items is simply the cumulative average cost of the n th item times n . However, it is important to understand all curves well enough to choose intelligently between them.

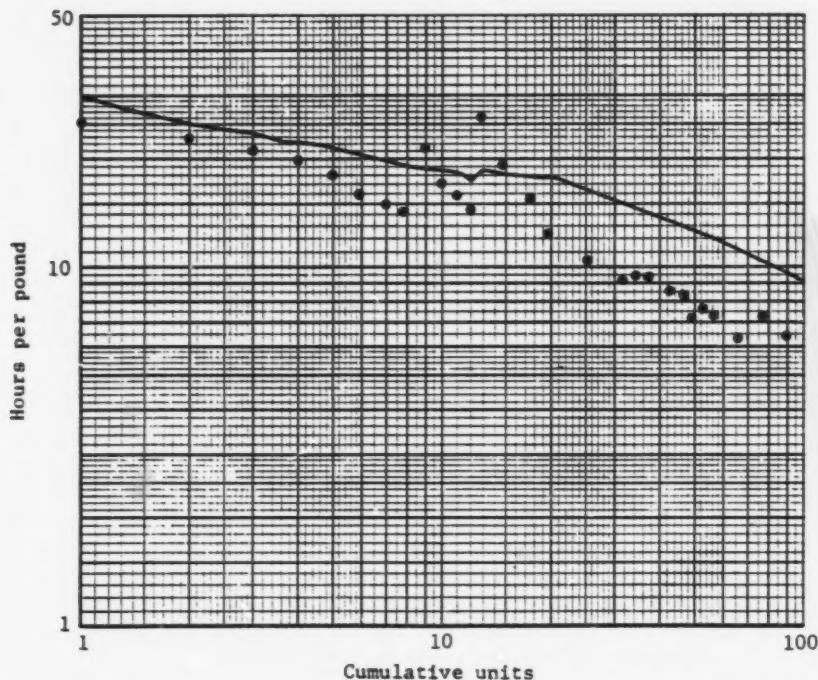


Figure 10. Smoothing Effect of Cumulative Average Curve

* Glenn M. Brewer, The Learning Curve in the Airframe Industry, School of Systems & Logistics, Air Force Institute of Technology, Report SLSR-18-65, August 1965.

5. APPLICATIONS.

The learning curve is used for a variety of purposes and in a variety of contexts; how the curve is drawn will depend on the purpose and the context. In long-range planning studies, for example, the curve must be constructed on the basis of generalized historical data, and the possible error is considerable. Empirical evidence does not support the concept of a single slope for all fighter aircraft, all solid propellant missiles, or all spacecraft. Therefore, the practice of assuming that manufacturing hours on the airframe will follow an 80-percent curve (as was common for many years) or that electronic equipment will follow, say, a 90-percent curve, can lead to very large estimating errors.

In regard to airframes, Table 2 shows the slope of the manufacturing-hour curves for 25 post World War II Air Force and Navy aircraft and indicates that a slope steeper than 80 percent is the rule. Since the learning-curve slopes of the table show important differences, it would be desirable to relate slope to aircraft characteristics. Such a relation is accomplished by a technique suggested by the Planning Research Corporation.* Separate estimating equations based on aircraft characteristics are derived for four different production quantities--10, 30, 100, and 300--and a learning curve is

Table 2

LEARNING CURVES FOR MANUFACTURING
(Labor for Airframe Only)

Aircraft	Learning Curve (%)
Fighter.....	77
Fighter.....	73
Fighter.....	74
Fighter.....	73
Fighter.....	78
Fighter.....	71
Fighter.....	74
Fighter.....	76
Fighter.....	77
Fighter.....	79
Fighter.....	82
Fighter.....	76
Fighter.....	75
Fighter.....	74
Bomber.....	76
Bomber.....	73
Bomber.....	70
Bomber.....	71
Bomber.....	79
Cargo.....	74
Cargo.....	78
Cargo.....	77
Cargo.....	75
Trainer.....	74
Trainer.....	75
Mean.....	75
Standard Deviation.....	2.7

SOURCE: G. S. Levenson and S. M. Barro,
Cost-estimating Relationships
for Aircraft Airframes, The
Rand Corporation, RM-4845-PR
(Abridged), May 1966, p. 56.

* Fixed-wing Airframe Costs.

developed from the estimates at these four points. However, on a theoretical level the concern is with aircraft characteristics that influence the rate of learning. It seems reasonable to expect relatively little learning for a model that represents a small modification over a preceding type, because the previous model would have already absorbed a considerable learning effect. On the other hand, if an aircraft contains radically new design features, a high initial cost is to be expected, followed by a rapid decline with increased production quantities. In other words, it has been suggested that the "newness" of an aircraft should be a major determinant of learning-curve slope, but explicit techniques for taking newness into account have yet to be developed.

For estimating to be effective, therefore, learning curves must be established on the basis of historical data relevant to the specific problem. Such curves are equally applicable to missiles, electronic equipment, aircraft, ships, and other types of equipment, but the slopes may be different for each of these. A recent study of avionics, for example, showed slopes ranging from 84 to 91 percent with a median value of 88 percent. If a comparison is being made between two weapon systems, one involving aircraft and the other missiles, the learning-curve slope chosen for each could play a significant part in the total system cost comparison. In the appendix to this chapter, the effect of slight variations in slope is shown to be much greater than is generally recognized. For example, the effect of using a 92-percent rather than a 90-percent cumulative average curve is an increase of 25 percent in the total cost of 1500 items. As one would guess, the situation is worse when steeper slopes are involved. If a slope of 62 percent instead of 60 percent is assumed, there is a 42-percent difference in the cost of 1500 items and a 25-percent difference in the cost of 100 items.* In practice, errors of this type can be minimized by originating the curve as the estimated cost of the 100th unit rather than at the first. Table 3 shows how this reduces the effect of a 2-percent change in slope on total cost.

Table 3
EFFECT OF VARYING SLOPE ASSUMPTIONS

Change in Slope	Change in Total Cost of 1500 Units (%)
From 90% to 92%	
Origin of curve:	
Unit 1	25
Unit 100	9 ^a
From 60% to 62%	
Origin of curve:	
Unit 1	42
Unit 100	14

^a If a log-linear unit curve is assumed, this value would be less than 6 percent.

Once a few data points are available either for developmental or production items, the situation should improve, but, as illustrated by Figure 11, the first few points may be misleading. Suppose an estimator had been asked to calculate the cost of a large production contract after the fabrication of the first 30 units. By fitting a curve to the existing data he would have projected a learning curve with an 88- or 89-percent slope and at a level considerably higher than that later experienced. In this situation it is important to realize that such a flat learning curve for airframe production is improbable. The estimator should have an idea of what the answer is likely to be and should investigate differences.

With a small sample of data, where a learning curve is fitted to a few points, the correlation may be perfect, i.e., all the points may lie on the fitted line, but the results can still be unreliable. The points used in fitting must be sufficiently numerous and reasonably homogeneous with the points implied by extending the curve to offer a reasonable probability of success in predicting costs.

*The assumption regarding the type of curve is important. For example, if a log-linear unit curve (rather than a log-linear cumulative average curve) were assumed, these differences would be only 25 and 13 percent, respectively.

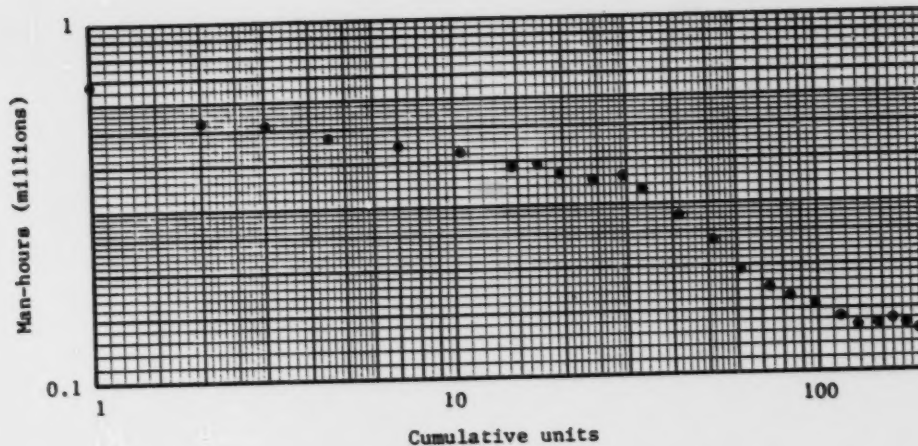


Figure 11. Direct Labor Hours for a Transport Aircraft

The manufacturing history of the item to be fabricated is the most valuable information the estimator can have. Variations from the norm may be caused by particular problems, configuration changes, or changes in manufacturing methods. In the curve of Figure 11, the initially flat portion (out to the 30th airframe) is explained by the manufacturer as being typical of the initial production period. In this manufacturer's experience, the curve begins to steepen when

- Manpower has stabilized or reached its peak.
- The engineering configuration has stabilized.
- The parts flow has stabilized.

Thus, it may be preferable to explain certain points and exclude them rather than to include them and bias the curve in height or slope.*

Whether to include all the points depends, in addition, on the anticipated use of the resulting curve. If a unit cost curve that includes all costs and changes is desired, a line of best fit through the unit plot points may be appropriate. If the curve is to be used in negotiating a follow-on contract, the effect of changes should be eliminated by constructing a curve through the lower portion of the plotted individual unit points, as in Figure 12. In effect, this assumes that the introduction of changes raises the hours initially but that these decrease again to the approximate level of the original curve.

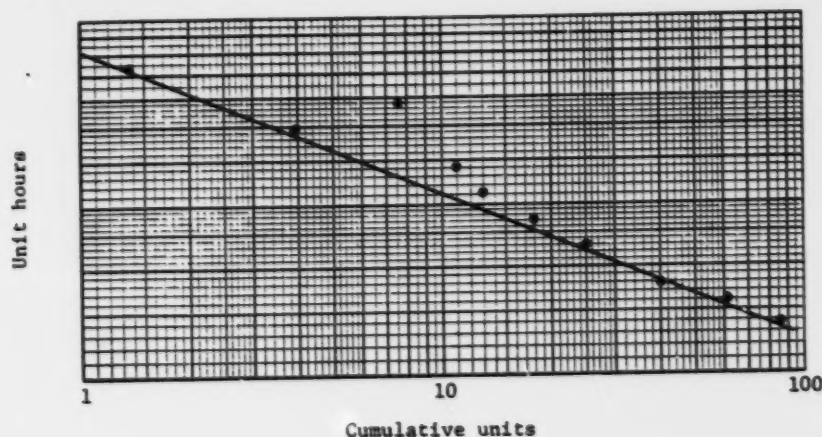


Figure 12. Effect of Changes on the Learning Curve

*It is possible to have a segmented unit curve, as implied by Figure 11, and several manufacturers subscribe to this concept.

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Whatever the basic technique, it is important to remember that on logarithmic grids the points at the right are usually more important than those at the left. In visually fitting a line, the analyst should avoid the tendency to be unduly influenced by plot points for small early lots. Early units are often incomplete because they are used for test purposes. It is equally possible that early units will include certain nonrecurring problems incident to startup and for this reason may be above the level suggested by later plot points.

Of course, variations in unit cost (or hour) data may happen for reasons other than the introduction of changes. An interruption in production can be an important factor. Interruptions may occur because of production cutbacks, labor disturbances, or funding problems. Whatever the reason, if significant time periods are involved, the learning curve will be affected in much the same way as illustrated in Figure 12. Those units produced after a significant amount of interruption can be expected to exhibit sharp increases in costs, followed by a recovery to the approximate projected level of the earlier preinterruption period.

APPENDIX

Assume a log-linear cumulative average cost-quantity curve of the form

$$y_c = ax^b, \quad (1)$$

where a is the cost of the first item produced,

x is the cumulative number of items produced,

b is an exponent that measures slope,

y_c is the average cost of all items produced up to and including x .*

It was shown previously that the learning-curve slope S describes the average cost of $2x$ items as a fraction of the average cost of x items and is related to b as follows:

$$S = 2^b \quad \text{or} \quad b = \frac{\log S}{\log 2}.$$

Substitution of this expression for b in Eq. (1) results in

$$y_c = ax^{(\log S / \log 2)}. \quad (2)$$

The cumulative average cost is only an input to the calculation of the total cost of x items; therefore, it is logical, for analytical purposes, to work with the total cost equation itself, which can be developed from the equation for the cumulative average cost as follows: y_c , the average cost of x items, when multiplied by x gives the total cost (T) of the same x items. If the required manipulations are carried out in symbolic form, the expression for T becomes

$$T = y_c x.$$

If Eq. (2) is substituted for y_c ,

$$T = ax^{(\log S / \log 2)} x,$$

and this can be simplified to give

$$T = ax^{[1 + (\log S / \log 2)]}. \quad (3)$$

At this point, observe that changes in the value of a are reflected directly in T . If the value of a were to increase 10 percent, the value of T would also increase 10 percent and furthermore do so independently of the value of either x or S .

The effect of x and S on T is more complex. Graphics can be used to show these effects rather than partial differentiation. Figure 13 portrays the solutions of Eq. (3) for values of S between .70 and 1.00, an a equal to 1, and x between 50 and 400, chosen to display the varying shapes of the different curves. It appears that as x becomes larger, T becomes more sensitive to changes in S . For example, a shift in S from 0.85 to 0.90 causes a \$16 change in the cost of 100 items and a \$65 change in the cost of 400 items.

An examination of these sensitivities in relative terms provides additional insights, as is often the case when dimensions are removed. Figure 14, a simplified copy of Figure 13, illustrates in part the calculation of an index (T_R) to measure the variation in T with respect to x and S . A value of S , designated S_N , and a corresponding value of T , also designated T_N , are selected. As the subscripts imply, these values are regarded as norms, or base points around which variation is allowed (indicated by shift to S and T). The index of relative change in T , T_R , is defined as the fractional change in T resulting from an absolute change in S , or in equation form,

$$T_R = \frac{T - T_N}{T_N} \quad \text{or} \quad T_R = \frac{T}{T_N} - 1. \quad (4)$$

* If a long-linear unit curve had been assumed, the outcome of this Appendix would be basically the same; however, the percentage variations shown in the following graphs would be of a lesser magnitude.

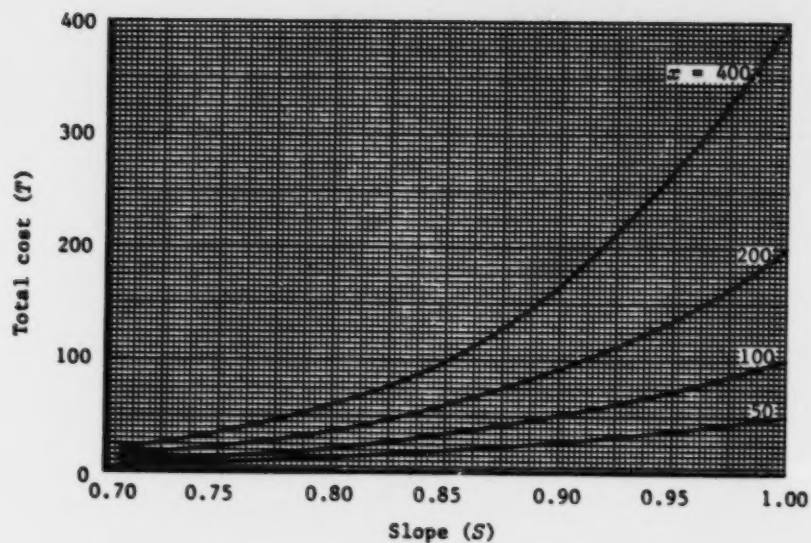


Figure 13. Effect on Cost of Changes in Slope

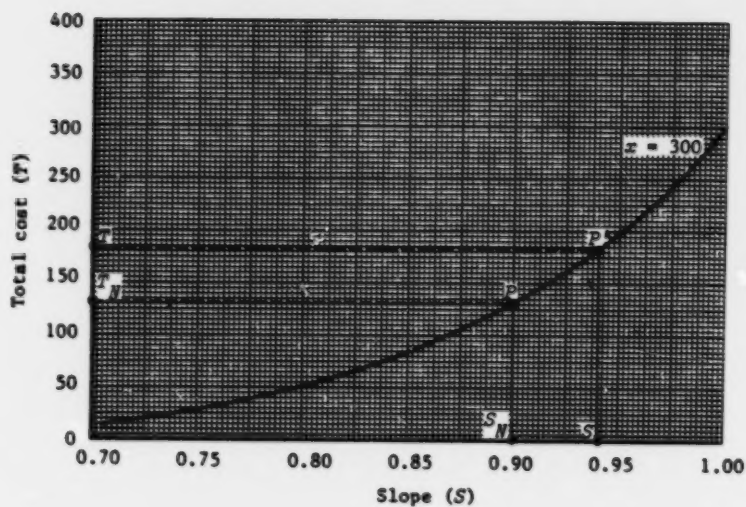


Figure 14. The Calculation of T_R

The following substitutions and simplifications result in the expression that was actually used to evaluate T_R :

$$T = ax^{(1+\log S/\log 2)},$$

$$T_N = ax^{(1+\log S_N/\log 2)},$$

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$$T_R = \frac{ax(1+\log S/\log 2)}{ax(1+\log S_N/\log 2)} - 1,$$

$$T_R = x(\log S - \log S_N)/\log 2 - 1. \quad (5)$$

The fact that the a's cancel out indicates that the sensitivity of T_R to S and x is independent of the value of a . Figure 15 shows the results of solving Eq. (5) if $S_N = .90$, $.86 \leq S \leq .94$, and $5 \leq x \leq 1500$ is assumed. The vertical axis T_R indicates decimal fractions of T_N by which T differs. The origin at the center allows changes both above and below T_N to be indicated. The horizontal scale S is similarly marked. Figure 16 presents a comparable display for steeper learning-curve values, i.e., $S_N = .60$, $.56 \leq S \leq .64$.

An examination of Fig. 15 shows that the relative difference between using an S of .90 and an S of .92 would be +25 percent in the total cost of 1500 items. Alternately, if an S of .89 rather than an S of .91 had been used, the difference relative to an average S of .90 would be approximately 23 percent.

If the same kind of exercise is carried out with Fig. 16, significantly greater differences result. For example, if an S of .62 instead of .60 is assumed, there is a 42-percent overstatement in the total cost of 1500 items and a 25-percent overstatement in the total cost of 100 items.

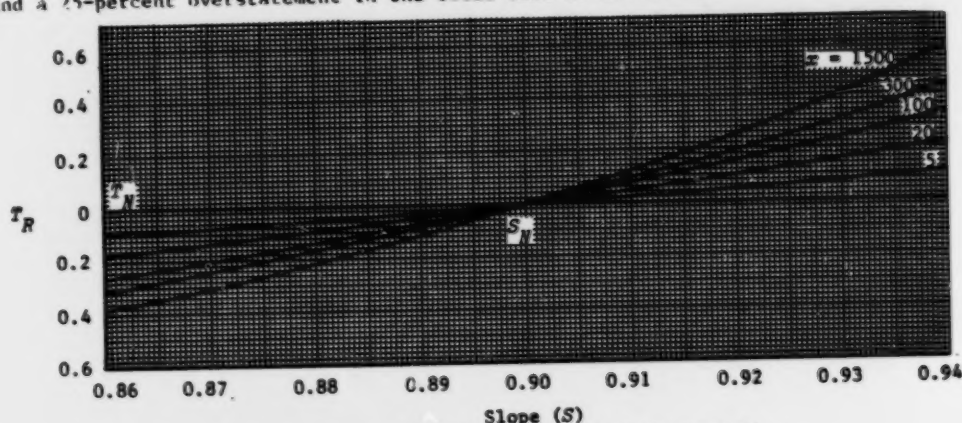


Figure 15. Values of T_R when $S = 0.86$ to 0.94

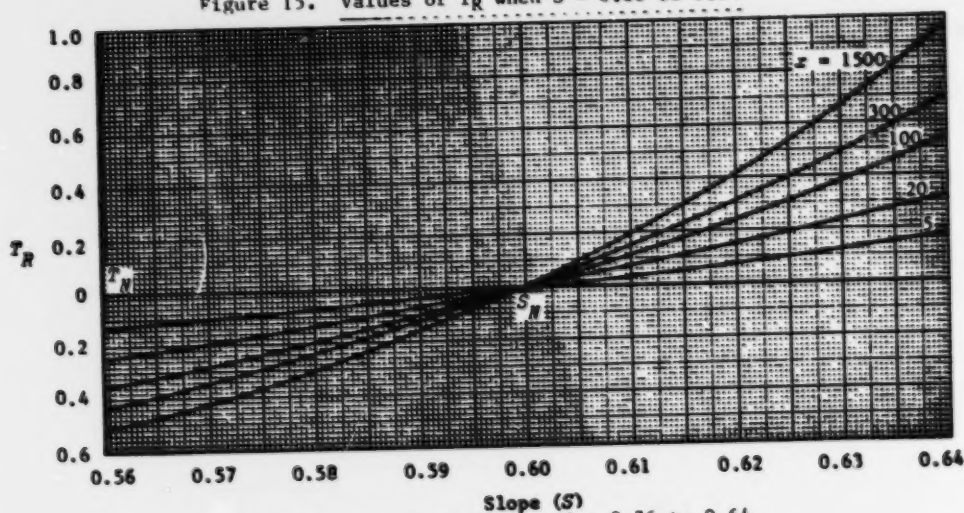


Figure 16. Values of T_R when $S = 0.56$ to 0.64

It must be concluded that when equations of this type are used to estimate cost as a function of quantity, significant percentage variations in the total cost can result from what are apparently much less significant changes in S . In addition, the impact of a unit change in S on T_R is inversely proportional to the size of S .

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CHAPTER 16

COST MODELS

The preceding chapter describes specific techniques for estimating production costs of aircraft. As supplemented by the earlier discussions of uncertainty and of estimating methods, it makes these points:

1. Cost estimating requires separate arithmetic operations, many of which must be performed in a specified sequence.
2. These operations in turn require numeric inputs, or selected descriptive details of the specific case for which the estimate is to be made.
3. Results of selected arithmetic operations are sometimes used as inputs for others in the estimation process.

It becomes apparent that if the above items are formalized, a specific methodology for obtaining cost estimates is the result--one that produces the same results when the same inputs are used. This formalized methodology is basically a cost model, which is the subject of this chapter.

1. DEFINITION OF A COST MODEL.

A cost model is a set of mathematical relationships arranged in a systematic sequence to formulate a cost methodology in which outputs (cost estimates) are derived from inputs (descriptions of the equipment, organization, or system). Cost models can vary from a simple one-for-aula model to an extremely complex model that involves hundreds or even thousands of calculations. As an example of a very simple cost model, the cost of an item might be related directly to its weight; that is,

$$C = DW,$$

where C = cost of item,
D = cost in dollars per pound of weight,
W = weight in pounds.

Here, D and W are inputs to the model and C is the output. Although this is a very simple model, it nevertheless performs the function of providing a cost estimate for given inputs.

Because the term cost model is used in various situations, it can have a variety of specific meanings. However, it still has the general connotation of an integrating device designed to facilitate the analytical process of obtaining cost estimates. In brief, it is a stylized representation of a part of the real world and can be used to gain insights into the cause-and-effect relationships existing in this world.

A distinction should be made between the term cost model and its representation in a computer program. Sometimes it is preferable to consider primarily the concept of the model and to treat the computer program as a less interesting tool. This distinction between the model and its representation on a computer may be especially useful in avoiding a tendency to focus attention on the wrong aspect--a common error when the advantages of a proposed cost model are being described. Speed, accuracy, and printed output are related to the computer, not to the use of the model. Although the term cost model is sometimes used to include the computer program, the advantages and limitations of cost models should not be confused with those of computers. (Computer cost models are discussed later in this chapter.)

2. TYPES OF COST MODELS.

Cost models can be classified in several ways. One basis for classification would be the complexity of manipulation of the inputs. On this basis, the very simplest cost model gives only a summary of facts provided by the analyst. The model may provide rules for subtotaling and totaling of information supplied as inputs. Models of this sort often use computers to perform the functions of adding machine and typewriter. A slightly more complex model may require a minor amount of multiplication in order to find a few intermediate values to be summarized and displayed. Somewhat more complex models may involve choices of estimating techniques that depend on specific inputs. The most complex models may involve fairly sophisticated analytical techniques, such as nonlinear programming or probabilistic iterations.

Cost models can be categorized according to the function they serve. Some models are designed to assist long-range planners; others are for use in programming, where this term applies a more detailed level of planning and application in the near future. Still others are designed for budgetary use. The function to be served influences the design of the model in many ways, with the level of detail to

be represented as one of the most obvious. A model designed for budget use would not usually be applied to long-range planning because it would require as inputs detail that is unavailable.

Cost models can also be classified according to the likelihood of repetitive use. Some are used for one application only. They may require considerable design and involved preparation of the input data, but they are developed for specific applications. Once the need has been met, the model is a thing of the past. It may still exist in files, and reference to it may be helpful in designing a later model. A model developed for a single use can be contrasted with a cost model designed to be used many times, and to give many cost estimates. The latter may require more care in design because of the likelihood that it will be used when the designer is not available; in other words, a model for general use should be user-oriented.

A cost model can be considered in the context of the subject matter that it is intended to represent. Some models deal with relatively minor parts of the total problem to be considered by a decisionmaker; others attempt to represent almost all of the problem areas faced by the decisionmaker.

- a. Advantages. Just as there are many kinds of models, so are there many kinds of benefits that can be obtained from models. In cost analysis, one of the most important functions of a model is that of providing a framework for analysis. The analyst finds that construction of a model requires precision, and that the need to identify each functional relationship imposes a discipline. The attempt to establish specific mathematical expressions aids the analyst in recognizing those elements of the total problem that require the most effort. The development of a model thus serves to give insight.

Isaac Newton observed that free-falling objects accelerated downward, and his observation can be expressed in a mathematical relationship, or a simple model:

$$d = \frac{1}{2} gt^2,$$

where $g \approx 32 \text{ ft/sec}^2$,

t = time of fall in seconds,

d = vertical distance fallen in feet after t seconds.

The model explains that gravitational acceleration at the earth's surface is about 32 ft/sec each second. This specific statement enables an observer to test Newton's hypothesis by comparing actual observations with the model's prediction. A cost model can be used similarly to test hypotheses about costs. The typical hypothesis, however, cannot be proved through use of a cost model; a series of tests can either show that it is unsatisfactory or let it remain as a reasonable hypothesis.

A model will give the same output when given the same inputs. This ability to reproduce outputs is a great advantage when compared with the use of unstructured best judgment to provide cost estimates. Both the user and the supplier of estimates usually prefer that a given problem yield the same result no matter how many times it is examined. Lack of reproducibility leads to lack of credibility.

The consistency of response inherent in cost models enables the analyst to make comparisons among alternatives. He can be sure that identical inputs are treated alike and that the differences in cost estimates (outputs) are based on differences in inputs. The ability to compare on a consistent basis is one of the most attractive features of cost models. However, the analyst must always be aware that the outputs are only as good as the assumptions of the model and the input data permit.

Cost-sensitivity analysis, an important analytical tool, tests the sensitivity of outputs to changes in one or more inputs. This is done usually through repetitive cost estimates that keep certain inputs unchanged while others are varied in a controlled manner.* This sort of analysis can be performed only if there is a technique for using the inputs to obtain cost estimates--in other words, only if there is a cost model.

Another important analytical tool is called contingency analysis. Instead of changing one input to the cost model, the analyst changes one or more aspects of the problem. Such a change can require that input parameters take on entirely different values. It might even require that the analyst change the basic assumptions of the model. In such cases, a more general model may be

*See the discussion on cost-sensitivity analysis in Chapter 6.

needed before estimates and comparisons of contingencies can be completed. Contingency analysis is another kind of sensitivity testing; it helps to show whether the item (or system or force) that is being costed is appropriate for only one contingency or for a range of contingencies. An unambiguous, reproducible set of estimates is essential for both sensitivity and contingency analyses.

A model is an excellent tool for organizing research. It highlights those areas of cost-analysis methodology needing improvement or further research. At the same time, it provides a device for incorporating the results of current research into the methodology depicted by the model.

- b. Limitations. The benefits that analysts can obtain by the proper use of cost models are impressive. However, there are undeniable limitations, and the development and use of cost models present problems that might not otherwise have to be met.

Most cost models are of expected value in nature (deterministic); i.e., estimating relationships are expressed as direct mathematical functions so that the output is determined specifically when the inputs have been furnished. The numeric values used as inputs and in the estimating relationships are best estimates or expected values that are intended to represent a real world that is not so easily reproduced. Estimating relationships always involve uncertainty. Unfortunately, the use of a deterministic model may encourage the analyst to feel that he has a technique for estimating the only output that is correct. Failure to recognize inherent uncertainty could be a serious error in analysis, and the use of expected-value models may make such failures more likely.

Cost models may be broadened to address the problem of uncertainty;* however, analysts have found a fairly strong demand for point estimates of cost. No matter what supplementary information the cost analyst wants to supply, he is usually asked for one best estimate of the cost of each item; and no matter how desirable probabilistic cost models may seem in concept, the working analyst continues to find that he is asked to use expected-value cost models.

The model designer selects essential relations to include in his model, and, unfortunately, the model user might readily develop the habit of thinking about only those relations represented in the model. Of course, he should always be aware that the model is a simplification and that its use involves the assumption that all outside relations are unimportant; e.g., Newton's model of a falling object neglects atmospheric drag. However, repetitive use of the same model may focus undue attention on those functions that are represented and may lead to the unexamined belief (or feeling) that no other functions can be of interest. For example, Newton's model also assumes g to be constant, although in fact, g is not exactly constant.

The preceding comments relate to problems that arise from misdirected attention on the part of the operator of a cost model. They are representative of an almost unlimited class of such problems. However, it can be argued that the use of a model does not necessarily increase the likelihood of misdirected attention. The advantages, or perhaps the necessity, of using cost models will usually outweigh the possible limitations. Models, as any tool, must be used with proper care, skill, and judgment.

3. MODEL MAINTENANCE.

A model must be an adequate representation of the current real world to be useful. An excellent model developed in the past to represent the world as it existed in the past may still be an excellent model of today's world; but the analyst who uses an existing model must be aware that, in effect, he is deciding that the model is still good. To make sure that his model will merit this confidence, the proprietor of a cost model must provide for continuing maintenance. He must make sure that the estimating techniques that are in the model not only continue to be of the correct functional form but that they also continue to have the best numeric values for all coefficients or parameters. He cannot have this assurance without a positive program to monitor relations in the real world. Every cost model imposes a duty on its operator. He must arrange (or be satisfied with existing arrangements) for an information system that can be expected to give appropriate notice when the model should be modified.

The need for information about values and relations that are inside the model is evident. A less obvious need is frequently a greater problem: The model operator must be ready to use the model for a fairly wide range of cases. This readiness requirement implies the availability of reasonable values for all inputs that might be needed. The model operator must have a continuing program that keeps him informed on the wide range of cases that can be studied using his model.

*P. F. Dienemann, Estimating Cost Uncertainty Using Monte Carlo Techniques, The Rand Corporation, RM-4854-PR, January 1966.

4. COMPUTER COST MODELS.

The application of computers to cost models offers many advantages to cost analysts who use these models. First, the computer is fast and accurate and relieves the analyst of much of the tedium of making numerous calculations (which also involve many chances for making errors).*

In addition to the obvious advantages of speed and accuracy, a computer cost model provides a useful documentation aid. Once the computer program is operable, the analyst has the cost methodology actually documented within the computer program. Cost-sensitivity analysis, which attempts to demonstrate the effect on the outputs of changes in the inputs, becomes much more practical when a computer model is available to examine a range of cases and numerous variations in each case.

Another advantage of a computer cost model is that in its development the analyst is often forced to make decisions that clarify potentially troublesome areas of his model, which cannot always be foreseen and which might be overlooked.** In other words, the computer cost model must be a precise, bounded framework of a specific methodology. Often, either in the programming or initial operation of a model, these areas (including illogical steps) are highlighted because many runs can be made on the computer to explore many kinds of situations.

A computer cost model program and data inputs may be stored in easily retrievable form on punched cards, tape, or disk. With occasional revision as the data and relationships require updating, they are available for use whenever necessary.

One of the disadvantages of using a computer cost model is that sometimes the model is almost too automated for the benefit of the user. A model can never be a substitute for the ability of the analyst to perform the estimating job, i.e., his ability to develop reasonable and realistic inputs based on judgment and experience. The analyst must continue to be aware that the outputs of the model are only as good as the inputs that produced those outputs; such outputs must always be judged in the context of the model that is used.

Generally, a large complex model that is to be used many times is the most suitable for programming on a computer. For a model that is developed for one specific application, the question of whether to program such a model for computer use depends on several factors. Basically, one must decide whether the advantages of the computer model would offset the time and effort required for programming and checking out such a model. For some operations, it might be advantageous to program the model even if it is to be used only once; in other cases, based on the judgment of the analyst, it might be more expedient to use a desk calculator.

In developing a computer cost model, the analyst often faces the need to communicate the description of his model to the computer programmer. The analyst must not only show all of the mathematical relationships in his model to the programmer, but, perhaps even more important, he must also show the sequence of operations. Specifically, he must show the logic of his model. It must be realized that a computer, like a person, performs only one calculation at a time. There are no parallel paths in a computer program where several calculations are performed simultaneously; therefore, all calculations must be shown sequentially.

One way that an analyst can communicate this information to a programmer is through use of flow charts that depict the sequence of operations through a program. Such charts can be used to depict various levels of operation. Usually, functional charts are constructed first to outline the general areas of calculations according to their functions within the program. Once these are established, charts may be constructed in greater detail, including the estimating relationships. Finally, a highly detailed flow chart may be prepared that depicts every step of the program, including loops for repetitive calculations.

Figure 1 shows a cost model flow chart that gives the sequence of operations for a computer program that encompasses the model used in Chapter 7 to calculate airframe development and production costs.***

*It should be noted that although the computer may be able to complete a job in a matter of seconds, the time required for developing and keypunching the inputs and for processing the outputs may create a total turnaround time of several hours or days.

**Other kinds of troublesome areas may exist in which estimating relationships are either unknown or seldom used. A computer program can provide for these by means of throughputs. A throughput is a data input that has been calculated outside of the computer and that is intended to be included in the final tabulations and summaries without further processing.

***H. E. Boren, Jr., DAPCA: A Computer Program for Determining Aircraft Development and Production Costs, The Rand Corporation, RM-5221-PR, February 1967.

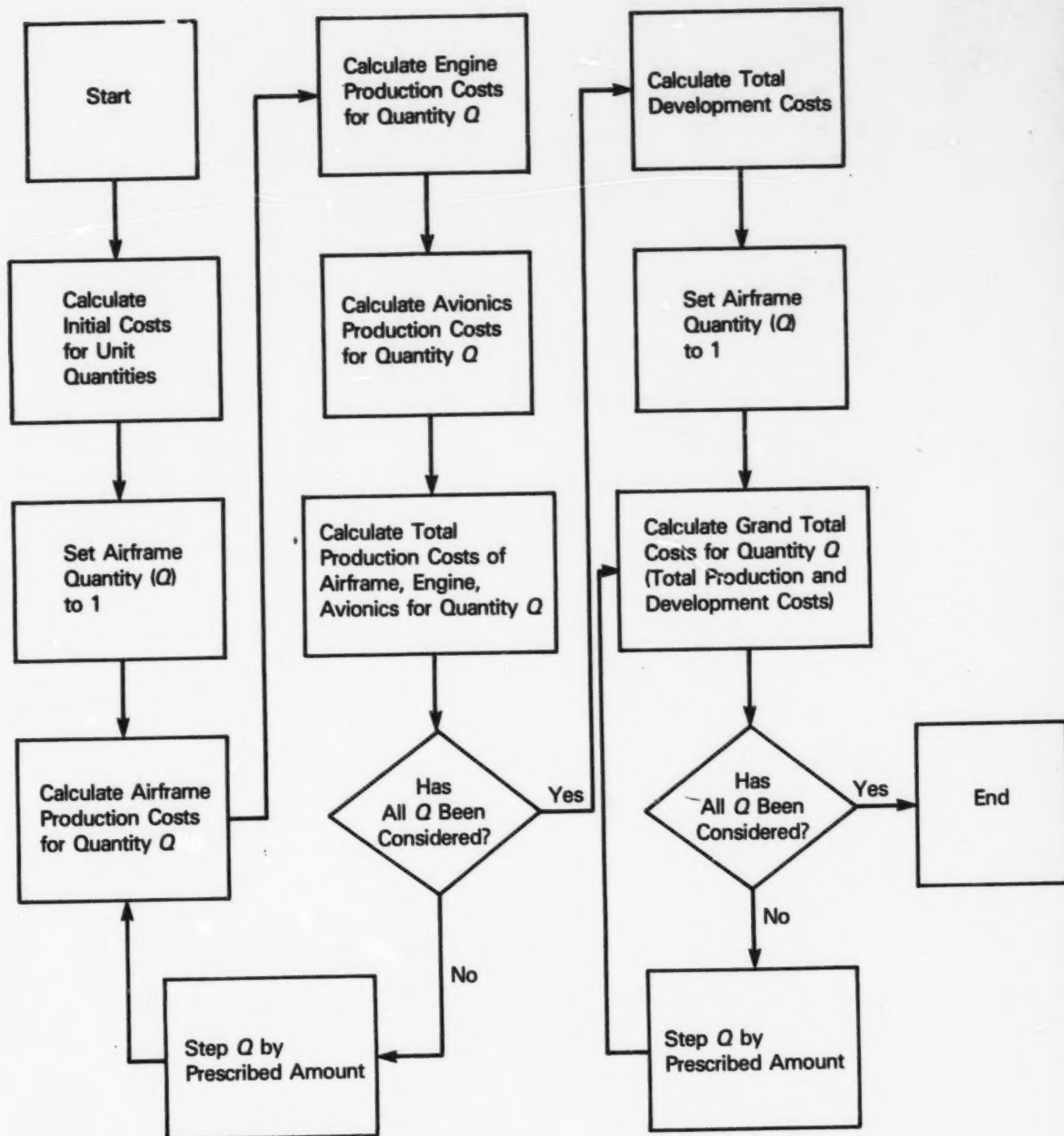


Figure 1—Computer Flow Chart of a Cost Model



In this figure decision points are represented by diamonds. At each decision point the path separates into two or more routes, and the computer goes along one of the new routes depending on the answer to the question asked within the diamond. This figure does not include program functions, such as reading-in the data and printing the output. These functions would usually be depicted later in more detailed charts prepared by the computer programmer for his own use.

Generally, in developing a detailed flow chart, the analyst need only ask himself: "If I were doing this problem by hand, what is the first step that I would perform; then what is the second step; what is the third step; etc.?" A computer performs in exactly the same way and needs to be told how to perform every step through a program.

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CHAPTER 17

COST DATA BASES

Cost data exist throughout the Department in various forms. In some cases, they are filed in warehouses collecting dust, and in other cases, the responsible office has converted the data for use by the local cost estimators. The following excellent example in Figure 1 illustrates how the INEL has compiled data for its users. All Operations Offices and Laboratories are encouraged to maintain this type of data base.

As mentioned previously, other cost data, at various WBS levels, are collected for parametric CERs. In this case, project performance and design parameters must also be collected in order to statistically find correlations between these parameters and cost.

(SAMPLE)

<u>Account No.</u>	<u>Description</u>	<u>Units</u>	<u>Low</u>	<u>High</u>	<u>Ave.</u>
4011	General Preparation of Site				
-1	Grading, Excavation & Fill				
1	Clearing & Grubbing	\$/Sq. Yd.	.05	.10	.08
2	Excavation (Earth)	\$/Cu. Yd.	2.10	3.00	2.70
	(Rock)	\$/Cu. Yd.	60.00	120.00	75.00
	(Disposal)	\$/Cu. Yd.	4.50	14.00	7.80
5	Grading	\$/Sq. Yd.	.30	.50	.40
6	Backfill & Fill	\$/Cu. Yd.	1.80	3.00	2.30
4012	Drainage				
-1	Grading, Excavation & Fill	(Use costs from 4011 Account)			
-2	Drain Pipe	(Use costs from 4011 Account)			
4013	Landscaping				
-1	Grading, Excavation & Fill	(Use costs from 4011 Account)			
-9	Landscaping				
-92	Sodding	\$/Sq. Ft.	.28	.34	.30
-93	Seeding	\$/Sq. Ft.	.06	.09	.08
4101	Roads				
-1	Grading, Excavation & Fill	(Use costs from 4011 Account)			
02	Paving & Surfacing				
1	Concrete	(Use costs from 4102 Account)			
3	Asphalt	\$/Ton	22.00	28.00	25.00
		\$/SF	0.41	0.52	0.46
6	Gravel				
	Pit Run	\$/Cy	3.85	5.40	4.60
	Crushed	\$/Cy	11.80	14.00	12.40
4102	Walks				
-1	Grading, Excavation & Fill	(Use costs from 4011 Account)			
-2	Paving & Surfacing				
1	Concrete 4" Thick	\$/SF	0.95	1.10	1.00
	6" Thick	\$/SF	1.40	1.60	1.50
4103	Paved Areas				
-1	Grading, Excavation & Fill	(Use costs from 4011 Account)			
-2	Paving & Surfacing	(Use costs from 4101 & 4102 Account)			
4104	Curbs & Gutters	N/A			
4105	Storm Sewers & Drainage	N/A			
4106	Bridges	N/A			

Figure 1

(SAMPLE)

<u>Account No.</u>	<u>Description</u>	<u>Units</u>	<u>Low</u>	<u>High</u>	<u>Ave.</u>
4107	Culverts				
-1	Grading, Excavation & Fill	(Use costs from 4011 Account)			
-2	Pipe Culverts				
	12" ϕ CMP	\$/LF	6.00	7.00	6.40
	18" ϕ CMP	\$/LF	8.00	9.00	8.50
	24" ϕ CMP	\$/LF	12.00	13.50	12.80
4201	Fences				
-1	Grading, Excavation & Fill	(Use costs from 4011 Account)			
-2	Fencing				
	Security	\$/LF	9.50	11.00	10.50
	Obstruction	\$/LF	3.00	5.00	4.50
4202	Guard Towers	N/A			
4901	Airports	N/A			
4902	Outdoor Rec. Facilities	N/A			
5011	Buildings				
-1	Grading, Excavation & Fill	(Use costs from 4011 Account)			
-3	Foundation & Substructure				
-32	Concrete				
	Footings	\$/CY	75.00	115.00	90.00
	Foundations	\$/CY	180.00	220.00	190.00
-42	Concrete				
	Slab on Grade	\$/CY	105.00	125.00	115.00
	Elevated Slab	\$/CY	345.00	400.00	385.00
-428	Precast Concrete				
	Double Tee	\$/SF	3.60	4.00	3.80
	Hollow Core	\$/SF	5.00	6.00	5.40
-43	Masonry				
	Exterior Masonry				
	Brick	\$/Sq. Ft.	2.10	2.75	2.50
	Block 8"	\$/Sq. Ft.	1.80	2.40	2.00
	12"	\$/Sq. Ft.	2.20	2.80	2.60
	Interior Masonry				
	Block 6"	\$/Sq. Ft.	1.65	2.00	1.80
	8"	\$/Sq. Ft.	1.80	2.40	2.00
-44	Steel & Metal Work				
-4411	Structural Steel				
	Heavy	\$/Ton	900.00	1300.00	1200.00
	Light	\$/Ton	1300.00	1600.00	1500.00
	Steel Joist	\$/Ton	1400.00	1700.00	1600.00
-4413	Grating	\$/SF	5.50	6.00	5.60
-4414	Misc. Steel	\$/Lb	0.85	1.20	1.00
-443*	Metal Siding				
	24/26 GA Painted	\$/SF	1.60	2.00	1.75
	Sandwich Wall	\$/SF	4.40	5.00	4.50
	Q Deck	\$/SF	1.40	1.75	1.60
-4461	Metal Doors				
	30 x 68 Non Rated	\$/Ea	180.00	220.00	190.00
	30 x 68 Rated	\$/Ea	350.00	400.00	360.00
	60 x 68 Non Rated	\$/Ea	400.00	450.00	420.00
	60 x 68 Rated	\$/Ea	900.00	1000.00	940.00
-45	Carpentry Work				

Figure 1 (continued)

(SAMPLE)

<u>Account No.</u>	<u>Description</u>	<u>Units</u>	<u>Low</u>	<u>High</u>	<u>Ave.</u>
-4511	Studding				
	Wood	\$/SF	.55	.75	.60
	Metal	\$/SF	1.00	1.25	1.10
-48	Surface Covering				
-4811	Built Up Roofing	\$/SF	2.30	2.70	2.50
-483	Insulation				
	Rigid 2" Thick	\$/SF	.90	1.10	1.00
	Blanket 3 5/8" Thick	\$/SF	.25	.35	.30
	Blanket 6" Thick	\$/SF	.40	.55	.45
-4854	Tile	\$/SF	.80	1.20	1.00
-4857	Carpet	\$/SF	1.20	1.50	1.30
-49	Painting & Glazing				
	Painting				
	Interior	\$/SF	.15	.22	.20
	Exterior	\$/SF	.35	.42	.40
	Decontaminable	\$/SF	1.10	1.55	1.25
	Glazing				
	Double Pane	\$/SF	5.00	9.00	7.00
5501	Other Structures				
-1	Grading Excavation & Fill	(Use Costs from 4011 Account)			
-3	Foundation & Substructure	(Use Costs from 5011-32 Account)			
-32	Concrete	(Use Costs from 4011 Account)			
-4	Supports or Structures	(Use Costs from 4011 Account)			
-41	Earth				
-42	Concrete Piers	\$/CY	200.00	240.00	220.00
-44	Steel	\$/Ton	900.00	1300.00	1200.00

Figure 1 (continued)

(SAMPLE)

TYPICAL FACTORS AND RATIOS

The following are rule of thumb estimating factors which are intended for use as checking guides. Complete estimates should not be made using these factors.

- (a) A typical construction project is 55 percent material and 45 percent labor.
- (b) Electrical transmission lines cost \$52,800.00 per mile.
- (c) A cubic yard of concrete requires 8 man hours for installation.
- (d) A building cost per sq ft and per cu ft are:

Warehouse	\$17.00/Sq Ft	\$1.15/Cu Ft
Office	\$42.00/Sq Ft	\$3.25/Cu Ft
Process Bldg.	\$30.00/Sq Ft	\$1.70/Cu Ft.
- (e) Fire sprinkler system cost \$1.00/Sq Ft.
- (f) 1" conduit and wire requires 1 man hour per 30 linear feet.
- (g) A normal heat load is 13 watts per sq ft of building at a cost of \$.20/Watt.
- (h) Transformers cost \$12,000 per M.V.A.
- (i) Foundations require an average of 120 # rebar per cu yard.
 Floor slabs require 65 # reinforcement per cu yard. Rebar cost \$.28 to \$.30 per pound fabricated and installed.

COST BREAKDOWNS

- 4011-11 Clearing & Grubbing: This is based upon removing a combination of grass, brush and shrubs. This standard cost is based upon 10,000 S.F. of area being removed. This does not include hauling of waste away from the area. The breakdown is as follows:

Equipment for 1 hour	= \$40.00
(2) Men 1 hour each at \$17.00/hr	= 34.00
Cost per hour	\$74.00
(1) Crew can clean 925 sq. yd. per hour	$\frac{74/\text{hr}}{925 \text{ SY/hr}} = \$.08/\text{Sq. Yd.}$

- 4011-12 Excavation: This is based upon the normal soil and rock conditions found at the INEL site. This standard Earth cost is based upon both bulk greavation using a bulldozer and the haul distances is 200' or structural excavation using a backhoe. The breakdown is as follows:

Bulk: Equipment for 1 hour	= \$100.00
(5) Men 1 hr. each at \$17.00/hr	= 85.00
Cost per hour	\$185.00
(1) Crew can excavate 68.5 cy/hr	$\frac{185.00/\text{hr}}{68.5 \text{ cy/hr}} = \$2.70/\text{cy}$

<u>Structural</u> : Equipment for 1 hour	= \$25.00
(2) Men 1 hour each at \$17.00/hr	= 34.00
Cost per hour	\$ 59.00
(1) Crew can excavate 22 cy/hr	$\frac{59.00/\text{hr}}{22 \text{ cy/hr}} = \$2.70/\text{cy}$

The standard Rock cost is based upon drilling, blasting and removing the rock from the excavation. The breakdown is as follows:

Equipment for 1 hour	= \$35.00/hr
(5) Men 1 hour each at \$14.00/hr	= 70.00/hr
Explosives and Handling	45.00/hr
Cost per hour	\$150.00/hr
(1) Crew can excavate 2 cy/hr	$\frac{150.00/\text{hr}}{2 \text{ cy/hr}} = \$75.00/\text{cy}$

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(SAMPLE)

COST BREAKDOWNS (continued)

The standard disposal cost is based upon loading loose material and hauling 10 miles to the dump. The breakdown is as follows:

Equipment for 1 hour	= \$44.00
(2) Men 1 hour each at \$17.00/hr	= 34.00
	\$ 78.00
(1) Crew can remove 10 cy/hr	$\frac{78.00/\text{hr}}{10 \text{ cy/hr}} = \$7.80$

4011-15 Grading: This is based upon final grading using 3 passes with a motor grader plus rolling. The breakdown is as follows:

Equipment for 1 hour	= \$ 55.00
(3) Men 1 hour each at \$17.00/hr	= 51.00
	\$106.00
(1) Crew can grade 265 sy/hr	$\frac{\$106.00/\text{hr}}{265 \text{ sy/hr}} = \$.40/\text{sy}$

4011-16 Backfill and Fill: This is based upon backfilling around piers, foundation and over pipelines. The fill is placed in control lifts and compacted to 95 percent density. The equipment used is a loader or bulldozer and a pan type compactor. The breakdown is as follows:

Equipment for 1 hour	= \$ 30.00
(5) Men 1 hour each at \$14.00/hr	= 70.00
	\$100.00/hr
(1) Crew can backfill 43.5 cy/hr	$\frac{100.00/\text{hr}}{4.35 \text{ cy/hr}} = \$2.30/\text{cy}$

4013-92 Sodding: This is based upon placing sod on 1000 SF. Included is unloading, placing and rolling on a prepared site. The breakdown is as follows:

Equipment cost per sq. ft.	= \$.02
Material cost per sq. ft.	= .18
Labor cost per sq. ft.	= .10
	\$.30/sf

4013-93 Seeding: This is based upon seeding 1000 sf. Included is raking, seeding and watering. The breakdown is as follows:

Material cost per sq. ft.	= .01
Labor cost per sq. ft.	= .07
	\$.80/sf

4101-23 Asphalt: This is based upon 2000 tons of plant mix. Included is transportation to the site spreading on a road, and rolling. The cost is based on a subcontract and is \$25.00/ton or \$.46/sq. ft.

4101-26 Gravel: Pit Run: This is based upon 100 cy of gravel out of the INEL pit. Included is loading, hauling, and spreading. The cost breakdown is as follows:

Material cost per cy	= \$ -0-
Equipment for 1 hour	= \$ 54.00
(3) men 1 hr/ea. at \$17.00 hr	= 51.00
	\$ 95.00
(1) crew can haul 21 cy/hr	$\frac{\$ 95.00/\text{hr}}{21 \text{ cy/hr}} = \$4.60/\text{cy}$

BEST DOCUMENT AVAILABLE

(SAMPLE)

COST BREAKDOWNS (continued)

Gravel: Crushed: This is based upon 20 cy of gravel hauled from a in town pit. Included is material loaded on trucks, hauling and spreading. The cost breakdown is as follows:

Material 20 cy at \$3.80/cy	= \$ 76.00
Equipment for 20 cy	= 95.00
(3) men 1.5 hr. ea. at \$17.00/hr	= 77.00
	<u>\$248.00/20 cy</u>
	= \$ 12.40/cy

4102-21 Concrete Walks: This cost is based on 200 SF. The cost includes concrete, forming, placing, finishing, stripping forms and clean up. The concrete walk is placed on a previously prepared base. The cost breakdown is as follows:

<u>4" Thick</u>	
Concrete 200 sf at 4" thick requires 2.25 cy concrete at \$48.00/cy	= \$108.00
Form material	= 8.00
Labor - Form .75 mh/cy x 2.5 cy	= 2.0 mh
Place .75 mh/cy x 2.5 cy	= 2.0 mh
Finish 1.00 mh/cy x 2.5 cy	= 2.5 mh
	<u>6.5</u>
6.5 mh x \$10.00/mh	= 84.00
Total cost 200 sf walk	<u>200.00</u>
	<u>\$200.00</u>
	<u>200 sf</u>
	= 1.00/sf

<u>6" Thick</u>	
Concrete 200 sf at 6" thick requires 3.75 cy concrete at \$48.00/cy	= \$180.00
Form material	= 16.00
Labor - Form .80 mh/cy x 3.75	= 2.95
Place .6 mh/cy x 3.75	= 2.25
Finish .75 mh/cy x 3.75	= 2.80
	<u>8.0 mh</u>
8 mh x \$13.00/mh	= \$104.00
Total cost 200 sf walk	<u>\$300.00</u>
	<u>\$300.00</u>
	<u>200 sf</u>
	= 1.50/sf

4107-2 Pipe Culverts: This cost is based upon a 20 foot length placed in an open trench. Excavation and backfill are not included. The cost breakdown is as follows:

<u>12" Diameter</u>	
Material 20 lf x \$5.00/lf	= \$100.00
Labor 2 mh x \$14.00/mh	= 28.00
	<u>\$128.00</u>
	<u>\$128.00</u>
	<u>20 lf</u>
	= \$ 6.40/lf

<u>18" Diameter</u>	
Material 20 lf x \$6.75/lf	= \$135.00
Labor 2.5 mh x \$14.00/mh	= 35.00
	<u>\$170.00</u>
	<u>\$170.00</u>
	<u>20 lf</u>
	= \$ 8.50/lf

<u>24" Diameter</u>	
Material 20 lf x \$10.35/lf	= \$207.00
Labor 3.5 mh x \$14.00/mh	= 49.00
	<u>\$256.00</u>
	<u>\$256.00</u>
	<u>20 lf</u>
	= \$ 12.80/lf

(SAMPLE)

COST BREAKDOWNS (continued)

4201-2 Fencing: Security. This cost is based upon 200 lf of 7' high chain link fencing. Included is post hole drilling, posts, fabric, top rail, outriggers, 3 strands barb wire and grounding all installed. The cost of \$10.50 per lf is on a subcontract basis.

Fencing: Obstruction. This cost is based upon 500 lf of 3'-10" high, 3 strand, barb wire fencing. Included is steel line posts, wood pulling posts, barb wire all installed. The cost \$4.50/lf is on a subcontract basis.

5011-32 Concrete: Footings. This is based upon placing 200 lf of 8" x 24" wide continuous footing at a single location. Included is forming, reinforcing, placing and finishing of the footing in a previously prepared excavation. The cost breakdown is as follows:

200 lf of footing 8" deep by 24" wide requires 10 cy of concrete.

Concrete 10 cy at \$48.00/cy	= \$480.00
Form material (based on 3 uses per form)	= 50.00
Rebar, 60#/cy x 10 cy x \$.30/# (installed)	= 180.00
Labor - Form .75 mh/cy x 10.0 cy	= 7.5 mh
Place .55 mh/cy x 10.0 cy	= 5.5 mh
Finish .20 mh/cy x 10.0 cy	= 2.0 mh
	15.0 mh
15.0 mh x \$120.00/mh	= 190.00
Total cost 10 cy footings	\$900.00

\$900.00
10 cy

Foundations. This is based upon placing 200 lf of 12" thick x 5' high foundation, gang formed, double whalters using metal forms. Included is forming, reinforcing, placing, finishing, striping forms, grouting and clean up. This foundation wall is based upon placement on an existing footing with the wall below grade. 2000 lf of foundation wall 12" thick by 5' high requires 37 cy of concrete.

Concrete 37 cy at \$48.00/cy	=1,780.00
Form material and rental 2000 sf at \$.45/sf	= 900.00
Rebar 120#/cy x 37 cy x \$.30/# (installed)	=1,330.00
Labor - Forms .08 mh/sf x 2000 sf	= 160 mh
Place .75 mh/cy x 37 cy	= 28 mh
Finish 1.2 mh/cy x 37 cy	= 33 mh
	232 mh
232 mh x \$13.00/mh	=3,020.00
Total cost 37 cy foundation wall	\$7,030.00

\$7,030.00
37 cy

= 190.00/cy